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CONTENTS

VOL. XV, PART II

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PAGE

Original articles—

STUDIES IN THE PERIODIC PARTIAL FAILURES OF THE PUNJAB-AMERICAN COTTONS IN THE PUNJAB. XIV. MINERAL METABOLISM OF NORMAL AND *TIRAK* AFFECTED PLANTS (WITH 15 TEXT-FIGURES)	*R. H. Dastur and Abdul Ahad*	63
STUDIES IN THE PERIODIC PARTIAL FAILURES OF THE PUNJAB-AMERICAN COTTONS IN THE PUNJAB, XV. FORMATION OF PROTEINS, OIL AND CELLULOSE IN THE SOILS OF NORMAL AND *TIRAK* AFFECTED PLANTS (WITH FIVE TEXT-FIGURES)	*R. H. Dastur and Abdul Ahad*	75
STUDIES ON STORED GRAIN PESTS IN THE PUNJAB, VI. BIOLOGY OF *TROGODERMA GRANARIUM* EVERTS (WITH ONE TEXT-FIGURE)	*Khan A. Rahman, G. S. Sohi and A. N. Sapra*	85
COLLAR ROT OF PIGEON PEA CAUSED BY *PYTHIUM APHANIDERMATUM* (EDSON) FITZ.	*R. P. Malik*	92
A NOTE ON THE DETERMINATION OF ORGANIC NITROGEN IN SOILS	*M. R. Madhok and Fazal Uddin*	93
THE BIOLOGICAL DECOMPOSITION OF GREEN MANURES, I. CARBON-NITROGEN TRANSFORMATIONS DURING DECOMPOSITION	*J. G. Shrikhande*	95
PROPERTIES OF SYNTHETIC MIXTURES, II. MIXTURES OF COLLOIDAL SOLUTIONS OF SILICIC ACID, ALUMINIUM HYDROXIDE AND FERRIC HYDROXIDE (WITH TWO TEXT-FIGURES)	*B. Chatterjee and A. Sen*	103
STUDIES IN INDIAN CEREAL SMUTS, VII. FURTHER STUDIES IN VARIETAL RESISTANCE OF INDIAN AND OTHER WHEATS TO LOOSE SMUT	*B. P. Pal and B. B. Mundkur*	106
STUDIES IN INDIAN CEREAL SMUTS, VIII. NOMENCLATURE OF INDIAN SMUT FUNGI AND PROBABLE MODES OF THEIR TRANSMISSION	*B. B. Mundkur*	108

ORIGINAL ARTICLES

STUDIES IN THE PERIODIC PARTIAL FAILURES OF THE PUNJAB-AMERICAN COTTONS IN THE PUNJAB*

XIV. MINERAL METABOLISM OF NORMAL AND *TIRAK*-AFFECTED PLANTS

By R. H. DASTUR † and ABDUL AHAD, Punjab Agricultural College, Lyallpur

(Received for publication on 3 April 1944)

(With 15 text-figures)

THE causes that give rise to the physiological disorder popularly known as *tirak* in the Punjab 4F American cotton plants have already been described in the previous contributions [Dastur, 1941; Dastur and Samant. 1942]. The main symptoms of *tirak*-affected plants are premature shedding of leaves and immaturity of seeds in the bolls. The premature yellowing of leaves on light sandy soils and drooping of leaves on soils with saline subsoils were found to occur in addition to the above-mentioned symptoms. It has been established that nitrogen starvation was associated with *tirak*-affected crop on light sandy soils, while unavailability of water produced *tirak* symptoms in cotton crop that came on soils with saline subsoils. Thus two different physiological causes led to the development of a common symptom, viz. immaturity of seeds. It has been demonstrated that yellowing of leaves on light sandy soils was associated with low nitrogen contents and development of *tirak* symptoms could be prevented by application of nitrogen in the form of the sulphate of ammonia [Dastur, 1941]. It was also shown that when nitrogen was applied to such soils there was an increase in the nitrogen content of leaves along with the absence of *tirak* symptoms [Dastur, 1941].

Though the chemical basis of premature yellowing and shedding of leaves was known, it was not known how the immaturity of seed and lint was caused. The chain of events that led to the immaturity of seeds and lint had to be therefore determined. Premature yellowing of leaves in plants on soils with saline subsoils did not occur even though the seeds remained immature on this type of soil as well. It was apparent that a physiological drought brought about the drooping and ultimate shedding of leaves on saline soils but the causes that produced immaturity of seeds and weak lint remained obscure. It was therefore necessary to investigate the internal causes that gave rise to these symptoms.

Tirak symptoms begin to appear only when the plants enter the fruiting phase. Before that stage the plants appear normal. In order to study the trends in the various metabolic activities of the *tirak*-affected plants it was necessary to make a chemical study of the plants from the seedling stage up to maturity, and this could not be done until the fields where *tirak* occurred were first located. Similarly the two soil conditions promoting *tirak* had to be differentiated before the investigation could be proceeded with. The investigation on the physiological chemistry of *tirak* was therefore dependent upon and was linked up with the investigation on other aspects of this *tirak* problem.

MATERIAL AND METHODS

In order to study the mineral uptake in the normal and the *tirak*-affected cotton plants, the fields which were previously known to possess the following types of soils were selected at the Lyallpur Agricultural Farm in the cotton seasons of 1938 and 1939, viz. (1) normal sandy loam, (2) sandy loams with saline subsoils, and (3) light sandy soil with nitrogen deficiency. Five plant samples were taken from each soil type at random at monthly intervals in 1938, and at fortnightly intervals in 1939. Root, stem, all leaves and fruiting organs were separately sampled and dried.

Similarly, samples of the leaves and bolls, etc. were also taken from a light sandy soil with nitrogen deficiency from the unmanured plots

*The work reported in this paper was done in the Punjab Physiological (Cotton Failure) Scheme financed jointly by the Indian Central Cotton Committee and the Punjab Government

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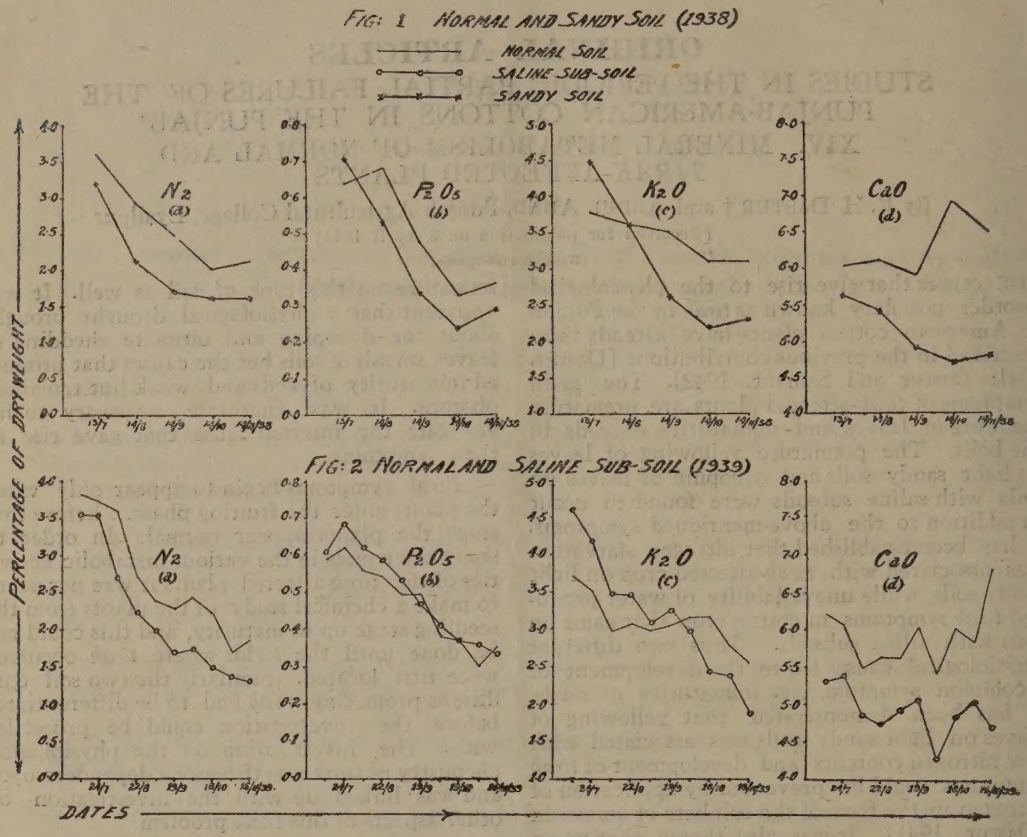
Percentage of different minerals in the leaves of 4F normal and *tirak*-affected cotton plants



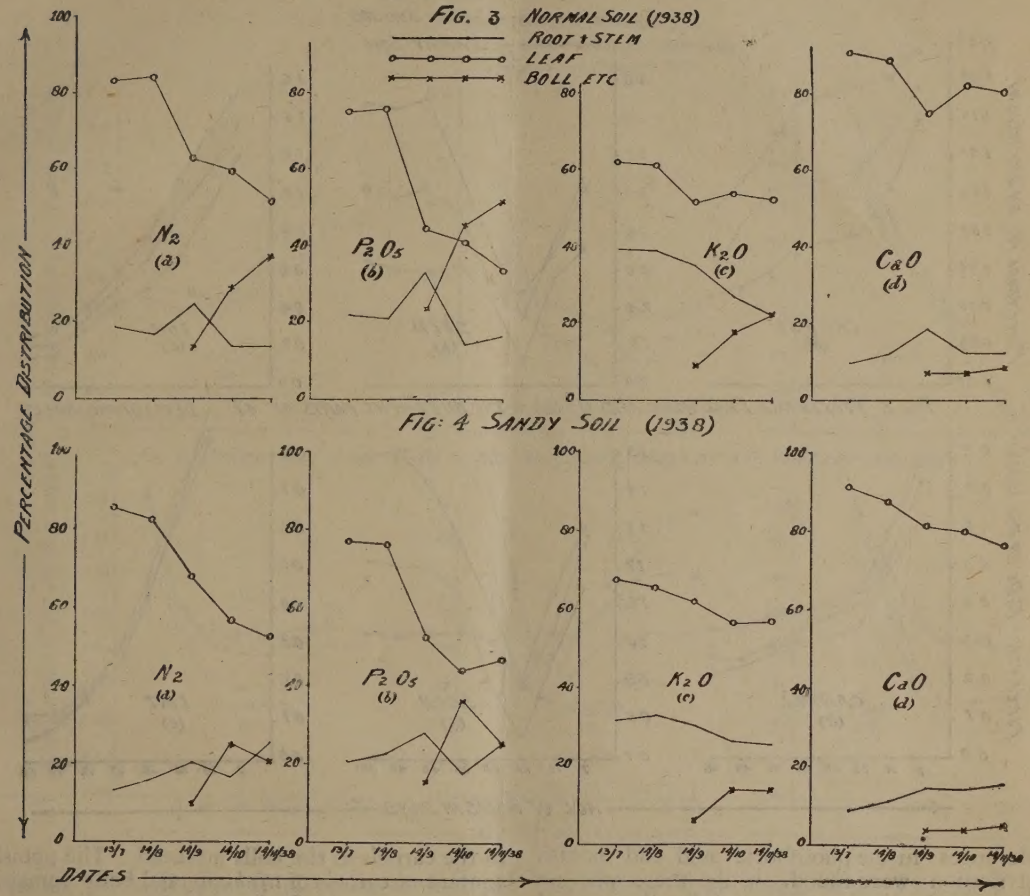
and from the plots where ammonium sulphate was applied. Samples were also taken at fortnightly intervals from the fields with normal soil and with soils with saline subsoils where cotton was sown at the usual sowing time in May and a month later, i.e. in June. The samples of developing bolls were taken at random from four plots of each of the three soil types at weekly intervals up to the eighth week of development in 1941. The first and the last samples were taken in duplicate from each soil type to see the variations due to sampling in the chemical composition of the material collected on the same day. The bolls were immediately weighed and divided into stalks, sepals, carpels, seed and lint. They were placed first in the electric drying oven, where a rapid draft of warm air was blowing at 45°–50°C. and then they were placed at 70°C. till the weight was constant. A representative part of each sample was dried finally at 100° C. to constant weight for the calculations of dry weight. Remaining parts of the samples which were already dried at 70°C. were powdered finely in the power knife mill and kept in the stoppered bottles for chemical analysis.

Total nitrogen was estimated by the modified Kjeldahl method to include nitrate nitrogen Calcium was estimated by the standard oxalate volumetric method and potash by sodium potassium-cobaltinitrite volumetric method. Phosphoric acid was determined by phosphoammonium molybdate method.

Investigation

The nitrogen, potash, lime and phosphoric acid were estimated in the roots, stems, leaves and the fruiting organs every month in the 1938 cotton season from the normal and *tirak*-affected

Percentage distribution of different minerals in the different parts of 4F normal and *tirak*-affected cotton plants



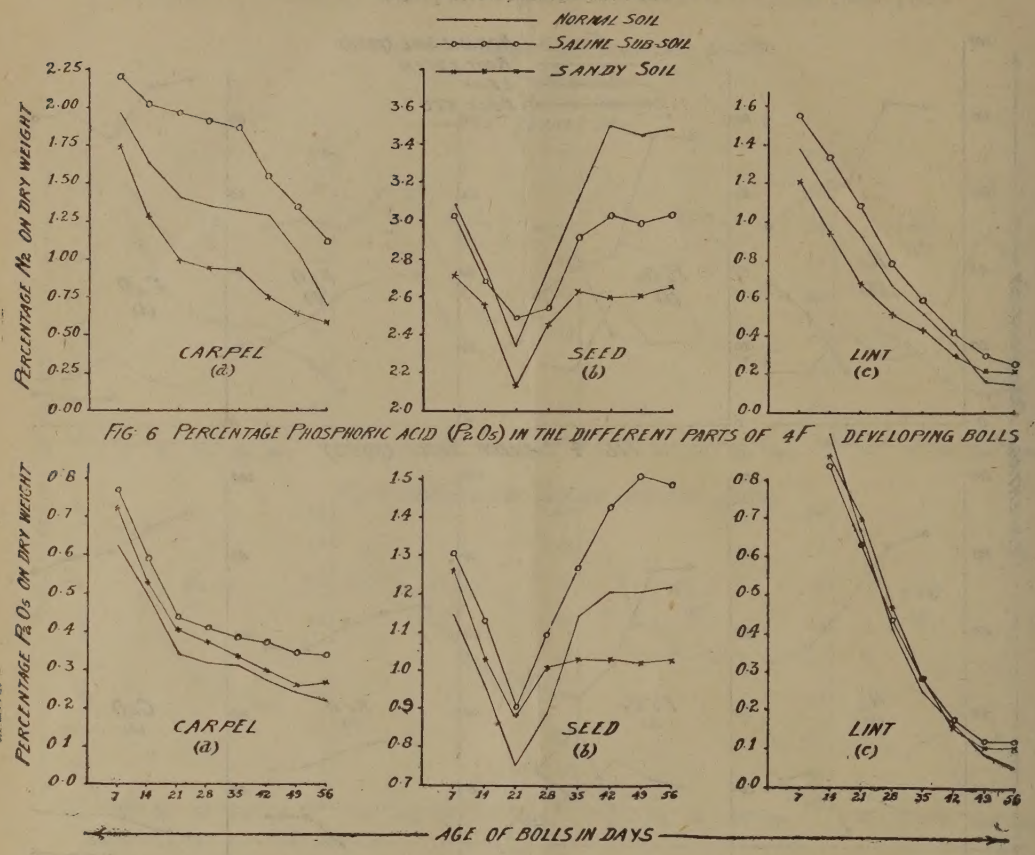
plants. The concentration of each mineral in each organ was determined on percentage oven-dry matter

Mineral composition of leaves

The stems and roots of normal and *tirak*-affected plants did not exhibit any marked differences at any stage in their chemical composition. Marked differences were, however, noticeable in the leaves from normal and *tirak*-affected plants (Figs. 1 and 2). The deficiency of nitrogen and lime were found to occur in the leaves of *tiark*-affected plants from the early stages of growth, while the deficiency of potash became marked from the mid August, i.e. in the preblooming stage in the case of sandy soils and from about the end of September in the case of saline subsoil. Phosphoric acid was low in the leaves of *tirak*-affected plants from light sandy soil only. The deficiency of nitrogen and potash was much more pronounced in the leaves of plants from light sandy soil than from the leaves of plants from the soil with a saline sub-soil.

When the percentage distribution of each element in the different parts, viz. root, stem, leaves and bolls was studied some important differences between normal and *tirak*-affected plants were found (Figs. 3 and 4). A comparison will show that the bolls of the normal plants contained more nitrogen (35 per cent of the total nitrogen absorbed by the plant) than the bolls of the *tirak*-affected plants, which contained only 20 per cent of the total nitrogen. Similar

Fig. 5. Percentage total nitrogen (N_2) in the different parts of 4F developing bolls



differences in the phosphoric acid and potash distribution were found, while there was no difference in the percentage distribution of lime in the bolls. The decrease in the percentage distribution of nitrogen, phosphoric acid and potash in the leaves at the fruiting stage indicated that these substances travelled from the leaves to the fruiting parts, where they were found to increase.

Mineral composition of bolls

A study of the concentrations of nitrogen, potash, phosphoric acid and lime in the carpels, seeds and the lint of normal and *tirak*-affected bolls at different stages of development revealed the following trends :

The concentrations of nitrogen (Fig. 5a), phosphoric acid (Fig. 6a) and up to a certain stage only, of lime (Fig. 8a) decreased while the concentration of potash (Fig. 7a) increased in the carpels as the bolls matured. The potash content of carpels of *tirak*-affected bolls remained constant in the final stages of growth.

The concentrations of nitrogen (Fig. 5b), phosphoric acid (Fig. 6b) and lime (Fig. 8b) showed a fall in the seeds during the first three weeks of development after which an increase in their contents was found to occur except in the case of seeds from light sandy soils where the first two elements remained constant after the 5th week. Potash (Fig. 7b), on the other hand, showed a continuous decline in the seeds of normal bolls, while it remained almost constant in the seeds of *tirak*-affected bolls after the 5th week of development.

The concentrations of all the four minerals decreased in the lint as it matured (Figs. 5c, 6c, 7c and 8c)

The following were found to be important differences between the mineral contents of

FIG 7 PERCENTAGE POTASH (K_2O) IN THE DIFFERENT PARTS OF 4F DEVELOPING BOLLS

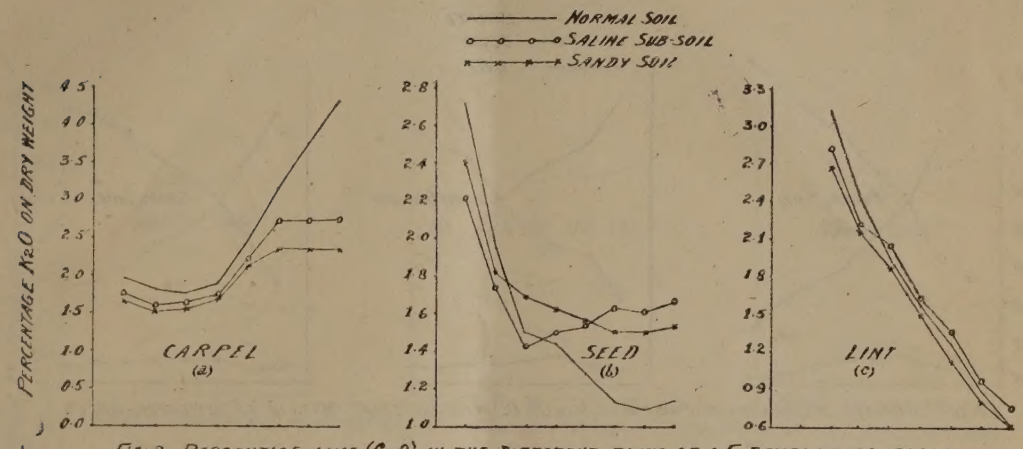
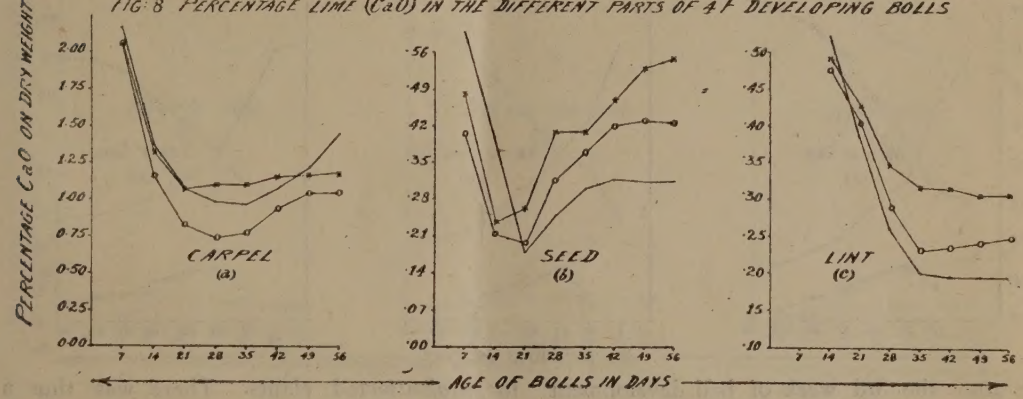


FIG 8 PERCENTAGE LIME (CaO) IN THE DIFFERENT PARTS OF 4F DEVELOPING BOLLS



normal and *tirak*-affected plants on the two soil types:

1. A low nitrogen content at all stages of growth in the carpels, seeds and lint was a feature of *tirak*-affected bolls on light sandy soils (Figs. 5a, 5b and 5c). The carpels and lint of *tirak*-affected bolls on soils with a saline subsoil, on the other hand, showed higher nitrogen contents than the corresponding parts of normal bolls at all stages of growth (Figs. 5a and 5c). That was not the case with seeds (Fig. 5b) which like the seeds from light sandy soils contained less nitrogen than the seeds of normal bolls after the 3rd week of development.

2. Phosphoric acid content was found to be below normal in seeds of *tirak*-affected bolls from light sandy soils in the last four weeks of boll development (Fig. 6b), while the same mineral was found to be present in larger concentrations than normal in the carpels of bolls from light sandy soils and in carpels and seeds from soil with saline subsoil (Fig. 6a).

The carpels of *tirak*-affected bolls were found to contain less potash at all stages than the carpels of normal bolls and this difference in the potash contents between normal and *tirak*-affected bolls became more pronounced in the final stages of growth (Fig. 7a). Potash content continued to increase in the carpels of normal bolls while it remained constant in the carpels of *tirak*-affected bolls during the last three weeks of boll development. The potash content of the seeds progressively declined in the normal bolls while it ceased to decrease in the seeds of *tirak*-affected bolls in the later stages of growth (Fig. 7b).

The lime contents of the seeds were higher in *tirak*-affected bolls than in the seeds of normal

FIG. 9 PERCENTAGE DISTRIBUTION OF TOTAL NITROGEN (N_2) IN THE DIFFERENT PARTS OF 4F DEVELOPING BOLLS

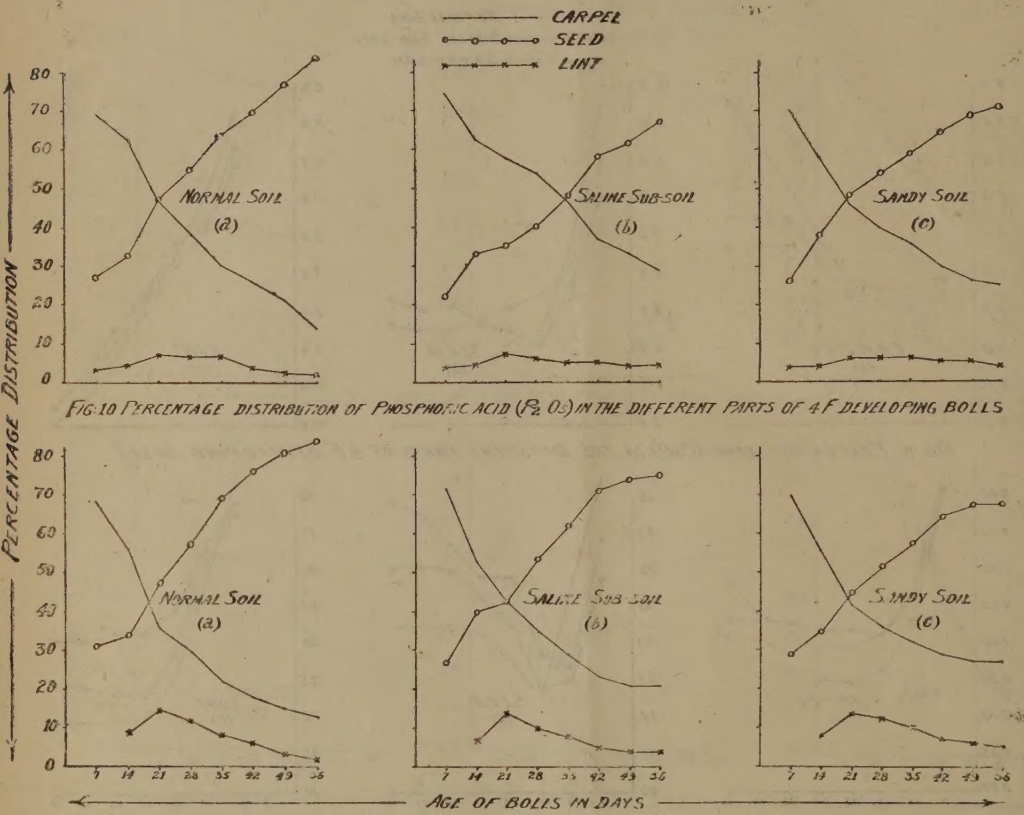


FIG. 10 PERCENTAGE DISTRIBUTION OF PHOSPHORIC ACID (P_2O_5) IN THE DIFFERENT PARTS OF 4F DEVELOPING BOLLS

(bolls after the 3rd week of boll development (Fig. 8b). Similarly the lime content of lint was higher in *tirak*-affected bolls than in normal bolls Fig. 8c).

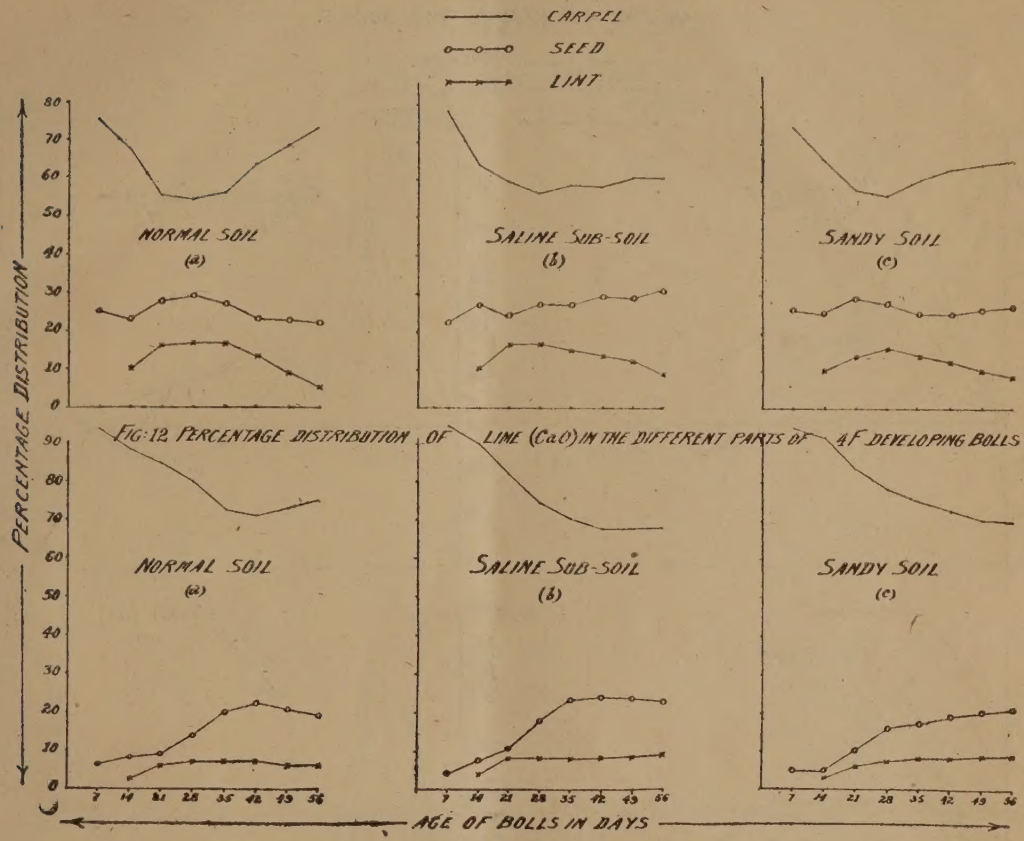
A low potash content in the carpels and a low nitrogen and a high potash and lime contents in the seeds were the common features in which *tirak*-affected bolls differred from normal bolls.

The graphs showing the percentage distribution of the four minerals in the different parts of the bolls of normal and *tirak*-affected plants are given in Figs. 9, 10, 11 and 12. The trends in the graphs are of two types, one type characteristic of nitrogen and phosphorus and the second type characteristic of potash and lime.

In the first type there was a progressive *decrease* in the percentage distribution of nitrogen and phophoric acid in the carpels, and an *increase* in the seeds as the bolls matured (Figs. 9 and 10). This held good for normal as well as for *tirak*-affected plants. There was thus a migration of these substances from the carpels to the seeds. In the case of *tirak*-affected bolls a greater percentage of nitrogen and phosphoric acid remained in the carpels at maturity than was found to be the case with the carpels of normal bolls. The seeds of *tirak*-affected bolls thus contained comparatively lesser percentages of total nitrogen and phosphoric acid than the seeds of normal bolls at maturity.

In the second type of curves (Figs. 11 and 12) there was a decline in the percentage distribution of potash and lime in the carpels during the first four weeks of development in all the three cases, after which there was no further decrease. An increase in the percentage distribution of potash in the carpels of normal bolls was found to occur in the last three weeks of development. There was no increase in the potash content of the seeds as they matured and the curves for carpels and seeds did not consequently intersect

Fig. 11. Percentage distribution of potash (K_2O) in the different parts of 4F developing bolls



each other. An increase in the percentage distribution of lime in the seeds of all the three types of bolls was found to occur up to the 5th week of development but after that stage it remained constant. No difference in the percentage distribution of the four substances was found to exist in the developing lint of normal and *tirak*-affected bolls.

The stages of growth at which the maximum amounts of these four substances enter the bolls were determined by calculating the percentage of the total uptake of each substance every week (Fig. 13). The maximum percentages of total nitrogen, phosphoric acid, potash and lime were found to be present in the bolls at the end of the second week. The uptake of nitrogen in *tirak*-affected bolls declined after the second week while it continued to remain high in the normal bolls. The curve for the uptake of phosphorus showed two maxima in the case of normal and *tirak*-affected bolls from saline subsoils, while the uptake of this mineral declined from the second week in the bolls from light sandy soils. The trends in the uptake of potash at different tages of growth of normal and *tirak*-affected bolls were similar to those discussed for nitrogen. The uptake of potash continued to be high up to the end in the normal bolls while it diminished after the second week of development in the *tirak*-affected bolls. No differences in the uptake of lime at different stages of development were found to exist between normal and *tirak*-affected bolls.

The uptake of nitrogen and the three minerals was found to be higher in first three weeks in *tirak*-affected plants than in the normal plants.

Discussion

As immaturity of seeds occurred in two different soil types it was possible that the chain

FIG: 13 PERCENTAGE INCREASE OF THE TOTAL UPTAKE OF DIFFERENT MINERALS IN THE 4F DEVELOPING BOLLS.

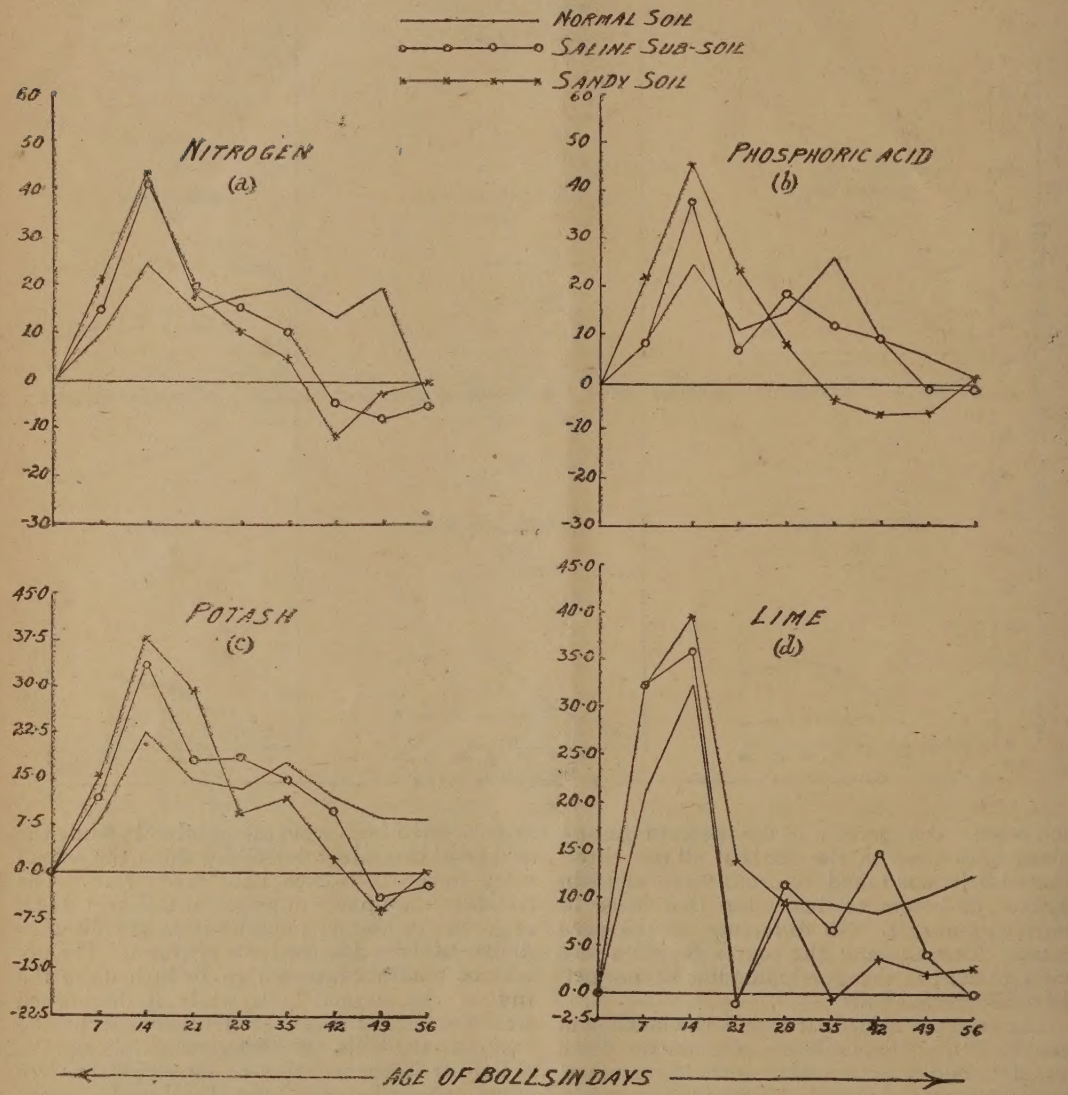
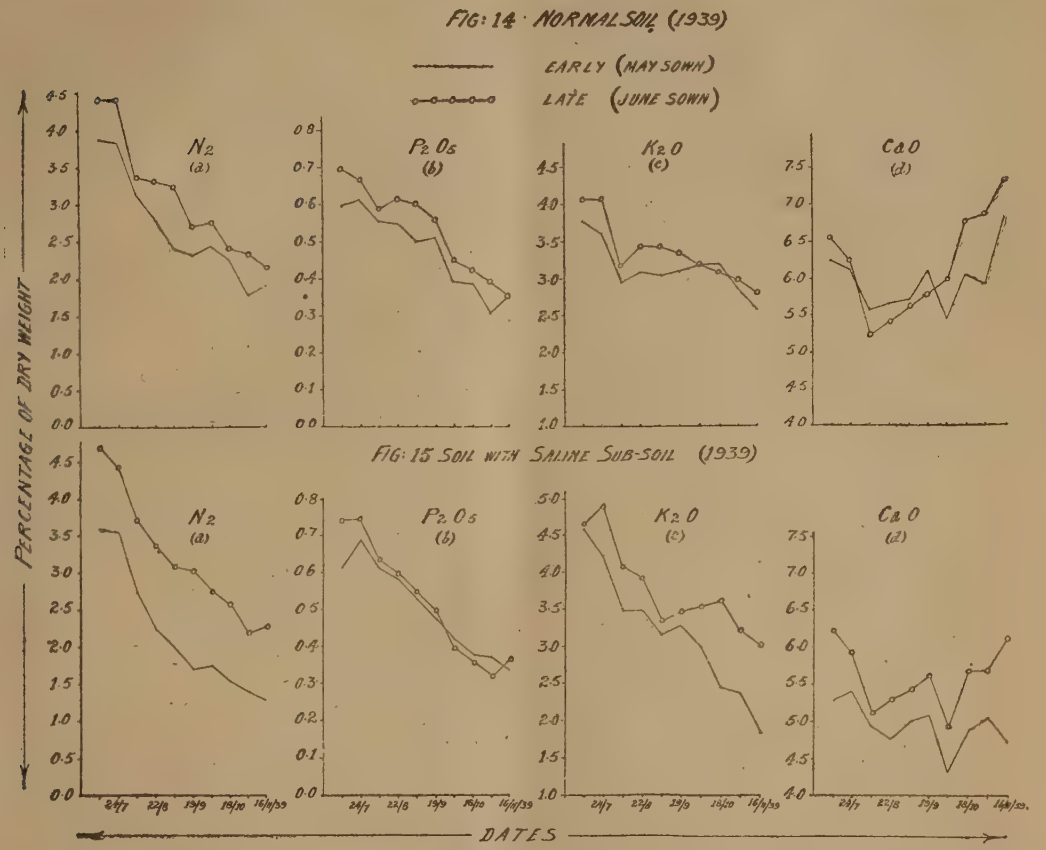


TABLE I

Percentage of potash in the leaves of control plants and of plants treated with 200 lb. of K_2O per acre

Treatment	Replicate number					Mean	S. E.
	1	2	3	4	5		
Control ..	2·82	3·25	2·92	3·49	2·97	3·09	0·059
200 lb. of K_2O per acre..	2·96	3·27	2·63	3·64	2·85	3·07	

Percentage of different minerals in the leaves of *early* and *late* 4F cotton plants on normal and saline subsoil



of events leading to the development of the common symptom on the two soils may be quite different. It may also be mentioned here that intensity of *tirak*, i.e. the degree of immaturity of seeds was greater on light sandy soils than on soils with saline subsoils. From the results discussed above it was clear that a greater disturbance in the mineral uptake was also noticeable in the bolls from light sandy soils than in the bolls from saline subsoils.

It has already been demonstrated by Dastur [1941] that applications of nitrogen in the form of the sulphate of ammonia to light sandy soils ameliorated *tirak* occurring on such soils. It was also shown, though not very conclusively, that when nitrogen was applied, there was an increase in the uptake of potash and lime by the plants along with that of nitrogen It therefore appeared probable that the uptake of potash and lime was influenced by the level of nitrogen in the soil. The deficiency of potash in the leaves and bolls and of lime in the leaves on light sandy soils may thus arise indirectly on account of deficiency of nitrates in the soil. It was therefore undertaken to establish this conclusion.

The leaves of the plants from plots in a field experiment where potash was applied at the rate of 200 lb. of K_2O per acre were analysed for potash along with the leaves of plants from control plots where potash was not applied. Five plant sample was taken for analysis from five control and five treated plots. The leaves from each plot were separately dried and analysed for potash.

Thus direct applications of potash did not increase its uptake, as no differences were noticed in the potash contents of the leaves of the control

and treated plants In addition the measurements of boll weight (i.e. the weight of seed cotton per boll) indicated no increase in the maturity of seeds of plants in plots treated with potash. Thus *tirak* condition was not ameliorated.

The application of nitrogen in the form of the sulphate of ammonia was found to ameliorate *tirak* and to increase the yields. It was therefore undertaken to determine the potash contents of the leaves and carpels from the control plots and from the plots treated with 50 lb. nitrogen in the form of the sulphate of ammonia. The leaves of five plants each, from four unmanured and four manured plots were taken for analysis.

TABLE II

Percentage of potash in the leaves and carpels of unmanured plants and of plants manured with sulphate of ammonia in light sandy soils

Plot	Leaves		Carpels	
	Unmanured	Manured with 50 lb. N	Unmanured	Manured with 50 lb. N
1.	2·36	3·26	3·20	4·27
2.	2·76	3·22	3·04	4·62
3.	3·06	3·76	3·11	5·28
4.	2·63	3·64	3·26	4·86
	2·70	3·47	3·15	4·76
S. E.	(± 0·085)		(± 0·159)	

The potash contents of the leaves and the carpels of plan ts manured with 50 lb. of nitrogen in the form of the sulphate of ammonia were significantly higher than the potash contents of the leaves and carpels of unmanured plants. It has already been shown that when nitrogen was applied, the nitrogen content of the leaves of manured plants was significantly greater than the nitrogen content of the leaves of unmanured plants at the same stage of development [Dastur, 1941]. There was also an increased uptake of lime as revealed by the analysis of the leaves of manured and unmanured plants [Dastur, 1941]. The results clearly suggested that potash and lime were not deficient in the light sandy soils but their uptake was lessened on account of the deficiency of nitrates in the soil. If the deficiency of nitrogen was made up by artificial application of nitrogen, the uptake of these minerals was greatly increased. Knowels, Watkins and Cowie [1940] found similar increase in potash uptake in the potato plant when nitrogen was applied.

The applications of nitrogen to light sandy soils were found to increase significantly the bearing, i.e the number of bolls per plant [Dastur and Mukhtar Singh, 1944]. Further investigations have shown that nitrogen had no direct relation with the seed maturity. In a field where the soil was light sandy as well as saline in the subsoil, i.e. where both *tirak*-promoting soil conditions were present, application of the sulphate of ammonia was found to increase the boll number per plant but did not reduce the immaturity of seeds as compared with boll number and seed immaturity found in the plants in the unmanured plots. The leaves of plants from treated plots did not exhibit the external symptoms of *tirak*, viz. premature yellowing and shedding but the bolls contained both partially and fully immature seeds [Dastur, Mukhtar Singh and Sucha Singh, 1944].

The application of the sulphate of ammonia to sandy loams (not deficient in nitrogen) with saline subsoils did not either increase the boll number or the maturity of seeds [Dastur and Mukhtar Singh, 1942] as compared with number and the seed maturity found in plants of the unmanured plots. Applications of potash did not also increase either the boll number or seed maturity. In no case application of lime was found to have any ameliorative effect on *tirak* on any soil type.

The results clearly indicated that there was no direct deficiency of potash or lime on the two soil types where *tirak* occurred. This fact was further confirmed by the determinations of exchangeable calcium and potassium from soils under normal crops and from soils under *tirak*-affected crops [Dastur and Samant, 1942]. No differences in either exchangeable calcium or potassium under normal and *tirak*-affected crops were found to exist.

A direct deficiency of nitrogen on light sandy soils reduced the uptake of potash on such soils. The case was different with soils with saline subsoils where a direct deficiency of nitrogen was not found to occur. In the former case immaturity of seeds was reduced by an application of nitrogen while that was not found to be the case in the latter type of soil. It therefore appeared probable that the immaturity of seeds was associated with the low potash content of the leaves and of carpels of *tirak*-affected plants.

The association of immaturity of seeds with low potash content has already been known to

occur in case of other crop plants,—Russell [1937] has pointed out that if potassium was deficient, grains of cereals did not mature. Neal and Gilbert [1935] reported that the application of potash remedied the disease of cotton known as 'cotton rust' or 'potash hunger' where the seeds remained immature. Skinner and Pate [1925] found an increase in boll weight as a result of potash applications in fine sandy soils. A decrease in weight of the seeds was reported by Wood [1934] when potash was omitted from manurial experiments. Schuster [1927] reported that soyabean plants grown with deficient potash supply produced small and immature seeds with low oil contents.

The cotton plants on soils with saline subsoil showed symptoms of physiological drought at the fruiting stage. The leaves drooped and were gradually shed. Here it was not primarily a case of a deficiency of nitrogen as the leaves did not show symptoms of nitrogen starvation, viz. premature yellowing. Application of the sulphate of ammonia did not produce any effect on seed maturity. The leaves drooped and were shed where even nitrogen was applied. It is probable that the roots in the saline layers of the subsoil did not normally function and the absorption of water and salts was interfered with. The leaves showed low nitrogen and lime contents at all stages of growth and a drop in the protash content from the flowering stage.

Though nitrogen was found to be low in the leaves, no deficiency of nitrogen in the carpels of bolls was found to occur. Though there was an accumulation of nitrogen in the carpels the potash content was below normal. Thus *tirak*-affected bolls from both the soil types showed a low potash content.

The deficiency of potash in the carpels of *tirak*-affected bolls was again confirmed by analysing the carpels of bolls from normal and *tirak*-affected plants. The choice of plants was perfectly random irrespective of soil conditions. The normal and *tirak*-affected plants were collected from different fields. The bolls from normal and *tirak*-affected plants were separately analysed.

TABLE III

Percentage of potash in the carpels of normal and tirak-*affected bolls*

	Number of samples analysed												Mean
	1	2	3	4	5	6	7	8	9	10	11	12	
Normal bolls ..	4·93	4·51	4·22	4 61	4·17	3·76	4·87	4·84	4·38	4·33	4·22	4·45	4·44
Tirak-affected bolls ..	2·61	2·22	2·34	2·06	2·37	2·85	2·94	2·81	2·75	2 83	2·86	3·04	2·64

(S. E. 0·095)

The potash content of the carpels of *tirak*-affectad bolls was found to be significantly lower than the potash content of the carpels of normal bolls. The difference between nitrogen contents of the carpels of normal and *tirak*-affected bolls were not constant. In some cases the nitrogen contents were higher and in other cases lower in *tirak*-affected bolls than the nitrogen contents of the normal bolls depending on the nature of the soil type from where the samples were collected.

The shift in the time of sowing of cotton from the month of May to the month of June has been found to be the best remedy for *tirak* on soil with saline subsoil. The delay in sowing is accompanied by a reduction in vegetative growth of the crop which does not suffer from a condition of physiological drought on such soils. The leaves do not droop and the seeds properly mature in the bolls[Dastur and Mukhtar Singh, 1942]. The ameliorative effect on *tirak* of June-sowing was found to be accompanied by a normal uptake of nutrients. The absence of drooping itself indicated normal absorption of moisture. The leaves of the May-sown and the June-sown plants on normal soils and on soil with a saline subsoil were analysed at fortnightly intervals from the early stages up to maturity, for nitrogen, phosphoric acid, potash and lime (Figs. 14 and 15). The nitrogen, potash and lime contents of the leaves of the June-sown plants were higher at all stages of growth than those of the leaves of the May-sown plants on soil with saline subsoil. The results indicated that a

June-sown crop was also able to function normally on the soils with a saline subsoil, and was able to obtain its normal requirements of water and salts.

Summary

A study of the mineral uptake of normal plants and of *tirak*-affected plants on the two soil types (a) light sandy deficient in nitrogen and (b) soil with saline sub-soil was made to determine if a deficiency of any important mineral was associated with immaturity of seeds in *tirak*-affected plants.

Detailed investigations of the chemical composition of leaves and bolls at different stages of development of normal and *tirak*-affected plants on the two soil types have revealed that a deficiency of potash occurred at the fruiting stage in *tirak*-affected plants. It was a common feature of *tirak*-affected plants occurring on both the soil types.

The deficiency of potash was found to occur indirectly as direct applications of potash were not found to increase its uptake or to increase seed maturity, The deficiency of potash in light sandy soils occurred as an indirect result of a deficiency of nitrogen. If nitrogen was applied the uptake of potash was also increased.

On saline soils the deficiency of potash probably developed as a result of the development of a condition of physiological drought. The absorption of water and nutrients was therefore reduced. If the condition of physiological drought was prevented in such soils by reducing the plant size by a shift in the time of sowing the uptake of nutrients of which potash was one was found to be normal. The leaves of the late-sown crop did not droop and the seeds and lint matured properly.

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STUDIES IN THE PERIODIC PARTIAL FAILURES OF THE PUNJAB-AMERICAN COTTONS IN THE PUNJAB

XV. FORMATION OF PROTEINS, OIL AND CELLULOSE IN THE BOLLS OF NORMAL AND *TIRAK*-AFFECTED PLANTS *

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(With five text-figures)

THE studies of the mineral uptake of *tirak*-affected plants indicated that a deficiency of potash on both types of soils was associated with the immaturity of seeds. On light sandy soils the deficiency of potash occurred indirectly as a result of deficiency of nitrogen while on saline subsoils it appeared to occur on account of the development of a condition of physiological drought which interfered with the normal absorption of water and other nutrients. Applications of nitrogen to light sandy soils were found to increase the uptake of potash and it was accompanied by a reduction in immaturity of seeds, while nitrogen application on soils with saline subsoils did not give similar results.

A deficiency of potash or nitrogen had already been known to cause a depression in the synthesis of proteins in plants and an accumulation of soluble forms of organic and inorganic nitrogen. The soybean and the pumpkin plants when starved of potash were found by Burrell [1926] richer in soluble nitrogen especially amino nitrogen than the control plants. Engel [1929] found a similar accumulation of soluble forms of nitrogen and a reduction of both total and protein nitrogen when nitrogen was deficient. Philips, Smith and Dearborn [1934] working on the tomato plant confirmed the findings of Burrell [1926]. They reported an accumulation of degradation products of proteins in the later stages of plant growth when potash was deficient. Walls [1940] who investigated the role of potasium in plants reported that the potassium-deficient tomato plant accumulated ammonia, amide and amino nitrogen, and showed a decrease in the protein nitrogen. Richards and Templeman [1936] and Richards [1938] working on barley leaves determined the changes produced in the protein and carbohydrate metabolism when nitrogen, potash, phosphoric acid and lime were not supplied in adequate amounts. They found that when potassium was deficient the protein nitrogen disappeared quickly from the leaves, a marked increase in the amino and amide nitrogen occurred and in the later stages nitrates accumulated. In the case of nitrogen-starved plants a fall in the level of nitrogen occurred with a corresponding fall in protein nitrogen. Gregory and Sen [1937] had concluded that potash deficiency caused an increase in the amino nitrogen, while a nitrogen deficiency produced a reduction in the protein nitrogen. Similar results as discussed above were obtained by Nightingale [1937]. An accumulation of amide, ammoniacal, and amino nitrogen and other related soluble compounds was found to occur when potash was deficient.

The above mentioned investigations clearly pointed to a disturbance in the protein metabolism of plants, when either potash or nitrogen was low. It was therefore considered necessary to study the protein metabolism of the bolls to determine if immaturity of seeds, the main symptoms of *tirak*, was in any way associated with a disturbance in the synthesis of proteins. The seeds from *tirak*-affected bolls were known to possess very thin and papery cotyledons devoid of oil. The cotyledons did not get filled up with oil when the seeds failed to mature. It therefore appeared probable that the synthesis of oil was also adversely affected. The study of oil formation and the stages at which oil formation in the developing bolls ceased in *tirak*-affected plants would provide information on the relationship of this process to the synthesis of proteins and consequently to the growth of bolls. The

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determination of physical and chemical constants of oil in the normal and *tirak*-affected bolls was considered of importance to determine whether the nature of the oil produced was the same or not.

This study of the fat metabolism of bolls would not be complete without a similar study of the carbohydrate contents in the developing bolls of normal and *tirak*-affected plants, as it was well known that oil was produced at the expense of carbohydrates. Caskey and Gallup [1931] have found that oil increased repidly in the cotton seed from the 21st day of the setting of the boll up to the 30th day while sugars decreased in all parts of the bolls as the development proceeded. These findings of Caskey and Gallup [1930] on cotton seeds agreed with those of Gerber [1897] on walnut and almond, of Ivanow [1911, 1912] on flax and rape seeds, of Rushkovski [1930] on sunflower seeds, of Eyre [1931] and of Johnson [1932] on the oil formation in the seeds of flax and of Sahasrabuddhe and Kale [1933] in niger seed. Reeves and Beasley [1935] who studied the development of the embryo of cotton seed found that sugars were present from the very beginning of the development of the embryo, while oil appeared during the 3rd week.

Materials and methods

As described in the previous contribution [Dastur and Ahad, 1944], three types of soils were selected for this study, viz. (1) Normal sandy loam, (2) Sandy loam with saline subsoils, and (3) Light sandy soil deficient in nitrogen. About 5000 flowers were tagged at the end of September in each soil type. Weekly samples of boll material were taken early in the morning from tagged plants. The samples were brought to laboratory and immediately weighed.

After sampling, the bolls were divided into various parts, viz. carpels, seeds and lint. Fresh weights, percentage of moisture and dry weights were determined from a part of the sample which was used for the determination of total nitrogen. For drying the samples electric ovens were used. For the determination of soluble fractions of nitrogen fresh material was used and the following procedure was adopted.

The method of squeezing out the juice by pressure from the frozen plant materials commonly employed with leaves and other tender parts could not be adopted in this case, as the carpels contained fibrous tissues and the seeds became dry and hard as they developed. Due to these practical difficulties, the grinding method of Davidson and Shive [1934] was finally adopted. About 25 to 50 gm. of the chopped fresh material was put in about 100 c.c. of boiling water to kill the enzymes. The material was then ground with water in a stone mortar and squeezed through muslin cloth in a beaker. This process of grinding and squeezing was repeated several times till all the soluble forms of nitrogen were removed. Two c.c. of 10 per cent acetic acid were added in the extract and it was boiled for one minute to precipitate any protein nitrogen left in th e colloidal form in the solution. After cooling, the solution was made up to 500 c.c., a few drops of toluene were added and it was kept in a refrigerator for 48 hours at a temperature lower than 5° C. so that most of the colloidal particles may settle down after chilling. The clear liquid was then used for the analysis of various soluble forms of nitrogen. Adequate quantities from the extracts, which were kept in the refrigerator, were taken for each analysis.

Total nitrogen and soluble total nitrogen were determined by the Kjeldahl-salicylic acid method modified to include the nitrogen of of nitrates. Protein nitrogen was calculated by diffenrence between the total nitrogen and the total soluble nitrogen. The nitrate nitrogen was determined by the modified phenoldisulphonic acid colorimetric method adopted by Frear [1930]. Ammoniacal nitrogen was determined by magnesium oxide method modified by Schlenker [1932]. Amide nitrogen was determined by the method of Tottingham *et al.* [1935] and α amino nitrogen by Van Slyke's method [1932]. Phosphotungstic method of Leonard [1936] was used for determining diamino and basic nitrogen.

Oil was determined by extracting the ground material with petroleum ether and its melting point by method of Jamieson [1932]. Abbe's Refractometer was used for determining the refractive index. Iodine, acid and saponification values of oil were determined by standard methods.

The fresh material was killed by immersing it in boiling alcohol to kill the enzymes. The soluble forms of carbohydrates were extracted with 80 per cent alcohol in a Soxhlet's apparatus for 24-30 hr. Alcohol was distilled off under reduced pressure at 40°C. and residue was dissolved in warm water. Basic lead acetate and sodium biphosphate were used for clarification. The extracted material was dried, finally powdered and passed through 100 mesh sieve for the determination of starch.

Reducing sugars and total sugars were determined by the Schaffer-Somogyi Copper volumetric micro-method modified by Heinze and Murneek [1940]. Starch was determined by Starch-iodide gravimetric method modified by Chinoy [1938]. Purified lint free from fats and sugar was estimated by the stardard chlorination method [Doree, 1933]. *α*-cellulose was estimated by gravimetric method after treatment with 17.8 per cent sodium hydroxide according to the technique recommended by the Committee of the Division of the Cellulose Chemistry of the American Chemical Society [1929]. β and 8-cellulose were determined from the filtrate of *α*-cellulose by potassium chromate-ferrous ammonium sulphate volumetric method according to Bray and Andrews [1923].

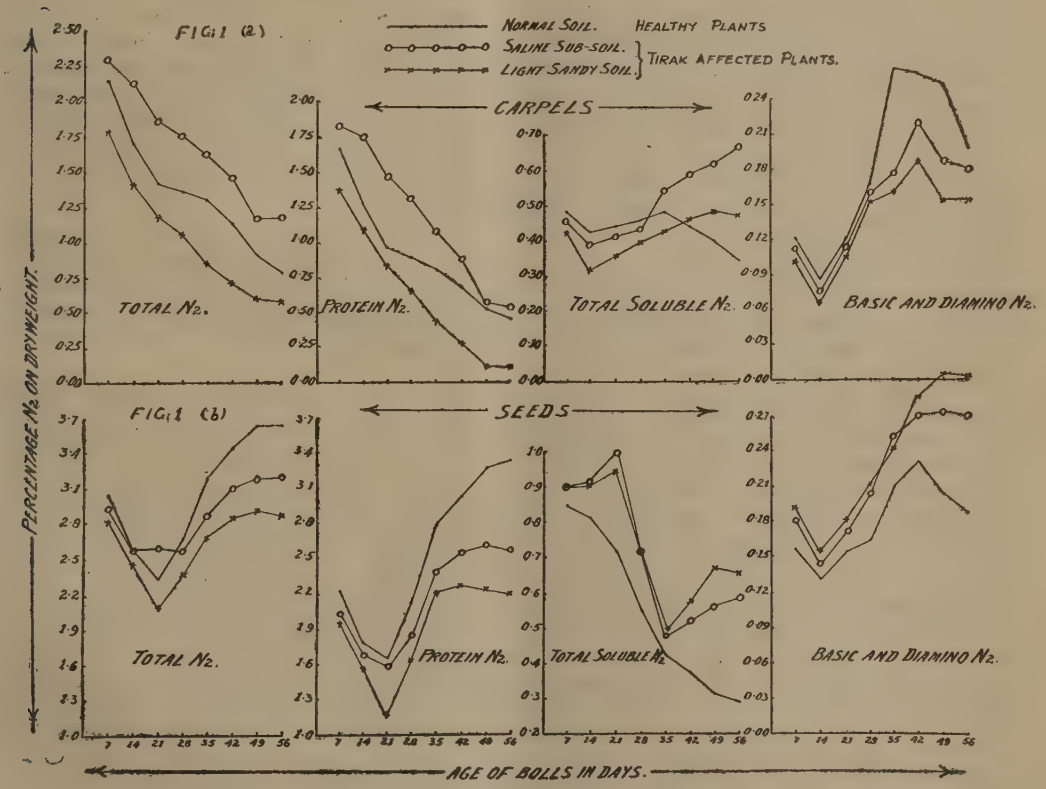
Investigation

Nitrogen metabolism

The trends in the total nitrogen and protein nitrogen contents in the carpels and seeds of bolls of normal plants and *tirak*-affected plants were similar (Fig. 1 a, b). The total nitrogen and protein nitrogen declined in the carpels as the bolls developed. The fall in the early stages may be due to a rapid increase in the dry weight of the carpels. There was a decrease in the total and protein nitrogen contents of the seeds up to the third week of boll development after which these contents increased in the seeds of normal as well as *tirak*-affected bolls (Fig. 1 a, b).

There were however marked differences in the concentration of total nitrogen and protein

Percentage of total N, protein N, soluble N and diamino N in the (*a*) carpels and (*b*) seeds of normal and *tirak*-affected bolls



nitrogen at different stages of growth between normal and *tirak*-affected bolls. The total nitrogen and the protein nitrogen in the carpels of bolls from saline subsoils were higher than

the similar contents in the carpels of normal bolls. Thus, nitrogen deficiency was not indicated in the carpels of the bolls from this type of soil. This difference already reported in the previous contribution [Dastur and Ahad, 1944] was, therefore, again confirmed. In the case of sandy soils total nitrogen and protein nitrogen in the carpels were found to be lower than those of the carpels of bolls from normal soil.

The total nitrogen and the protein nitrogen contents were highest in the seeds of normal bolls; medium in the seeds of *tirak*-affected bolls from saline subsoils; and lowest in the seeds of *tirak*-affected bolls from light sandy soils. The protein nitrogen did not show much increase in the seeds of *tirak*-affected bolls from the two soil types in the last three weeks of development. The synthesis of proteins in the seeds of *tirak*-affected bolls appeared to cease at the end of the fifth week.

The trends in the concentration of soluble nitrogen in the seeds and the carpels of bolls from the normal and *tirak*-affected plants were found to be quite different. In the carpels of bolls from normal plants the soluble nitrogen decreased from the 5th week, while it increased up to the last stage of development in the carpels of *tirak*-affected bolls (Fig 1 a, b). The soluble nitrogen in the seeds of normal bolls showed a continuous decline from the 1st week up to the 8th week of development (Fig. 1 b) while it showed an increase in the seeds of *tirak* affected bolls from the 5th week of development. The conversion of soluble nitrogen to protein nitrogen did not, therefore, occur in the seeds of *tirak*-affected bolls from the 5th week of development. The accumulation of soluble nitrogen in the bolls of *tirak*-affected plants began a week before the protein synthesis ceased. The protein metabolism of *tirak*-affected bolls was therefore not found to progress normally from the 5th week of development

The curve showing the diamino nitrogen in the carpels and seeds of normal and *tirak*-affected bolls (Fig. 1 a, b) indicated that the synthesis of proteins in the *tirak*-affected bolls ceased at the diamino stage. The diamino nitrogen in the carpels of normal bolls was higher in the last four weeks of development than the same form of nitrogen in the carpels of bolls of *tirak*-affected plants, while reverse was the case in the seed. The soluble nitrogen in the carpels and seeds of normal bolls chiefly consisted of diamino nitrogen which appeared to be converted into proteins.

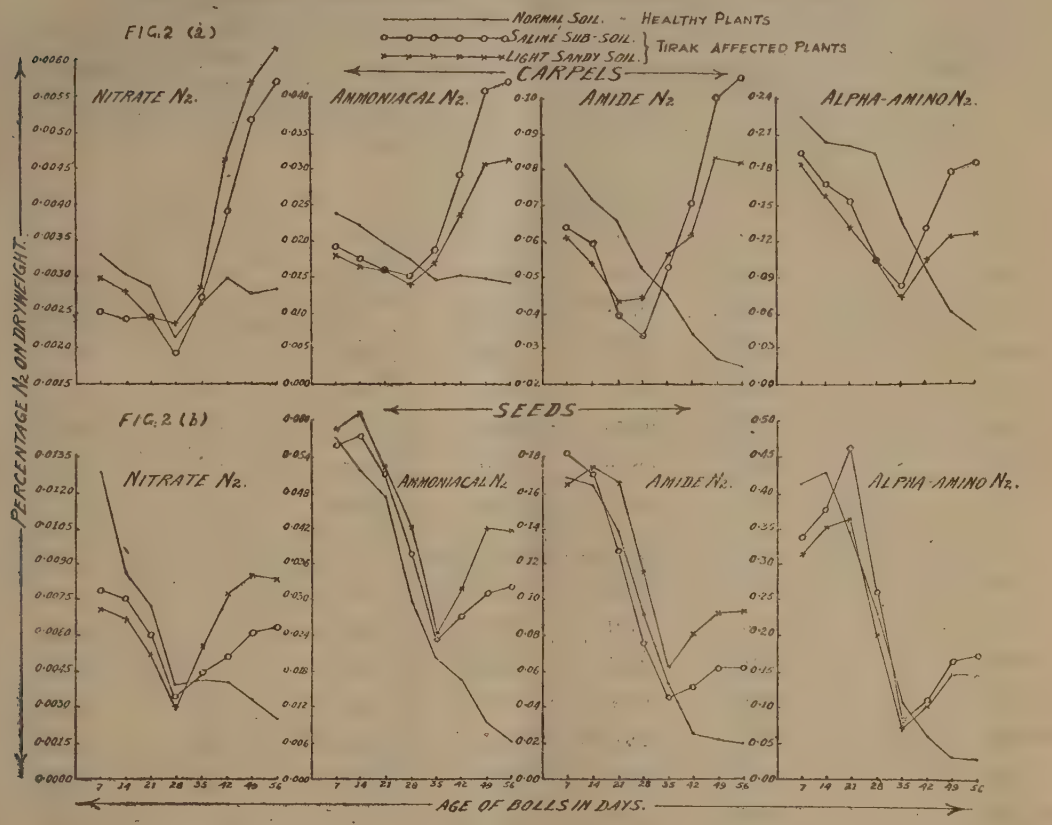
The other fractions of soluble nitrogen in the carpels and seeds of normal and *tirak*-affected bolls showed similar differences from the 5th week of development. Up to the 5th week the curves of nitrate, ammoniacal, amide and amino nitrogen were of descending nature, showing that these compounds did not accumulate in the bolls and the protein metabolism proceeded normally in all bolls. But after the 5th week of development these soluble fractions began to accumulate in *tirak*-affected bolls (Fig. 2, a, b). Amide nitrogen and amino nitrogen showed a continuous decrease in the seeds and carpels of normal bolls, while they accumulated in the carpels and seeds of *tirak* affected bo ls from the 5th week of development. The accumulation of nitrate nitrogen was found to occur a week earlier (Fig. 2 a, b).

The above results suggested that accumulation of nitrate and ammoniacal nitrogen started in *tirak*-affected bolls during the 5th week of development. This was followed by an accumulation of soluble organic nitrogen during the 6th week and after. This was in turn accompanied by a cessation in the synthesis of proteins at the same stage in the seeds of *tirak*-affected bolls. The disturbance in the protein metabolism in the bolls of *tirak* affected plants could, therefore, be said to occur, when the bolls were about five weeks old.

The total nitrogen and the protein nitrogen contents of *tirak*-affected bolls from light sandy soils were lowest at all stages of development. This may be due to a deficiency of nitrogen and potash occurring together in the plants on this type of soil.

The lint of the bolls, from the three soil types were analysed for total nitrogen, protein nitrogen and soluble nitrogen. The total nitrogen in the lint decreased as the lint matured. This was also found to be the case in the carpels. There was, however, a temporary increase in the protein nitrogen in the first three weeks of development after which there was a decline. The temporary rise in the protein nitrogen in the lint in the first three weeks may be due to maximum production of new hairs during that period, after which formation of new hairs did not occur. As these newly formed hairs were living and filled with protoplasm, the protein nitrogen contents were also high. In the later stages the hairs elongated and thickened and most of the cell contents disappeared whereby a decrease in the percentage of total nitrogen, protein nitrogen and soluble nitrogen occurred.

Percentage of nitrate N, ammoniacal N, amide N and alpha-amino N in (*a*) carpels and (*b*) seeds of normal and *tirak*-affected bolls



Fat and carbohydrate metabolism

The results of oil contents and the different constants of oil are given in Table I. The ether extract of the seeds in the first three weeks of development consisted of a waxy substance of a high melting point fluctuating between 52°C. to 55°C. The real oil formation started from the 4th week of boll development in the case of normal plants and of *tirak*-affected plants on light sandy soils while oil appeared a week earlier in the seeds of *tirak*-affected plants on soils with saline subsoil. The oil formation ceased in the 6th week in seeds of *tirak*-affected plants while it continued to increase up to the 8th week in normal plants, i.e. when the bolls opened. The quantity of oil formed per 100 gm. of seeds in *tirak*-affected plants was less than in the seeds of normal plants.

The melting point of the ether extract was gradually lowered as the seeds developed till it reached a value of 2°C. to 3°C. at maturity in seeds from normal as well as *tirak*-affected plants. There was an increase in the saponification and iodine values of the ether extract as the seeds matured indicating that the fatty acids of low molecular weights and the unsaturated fatty acids in the oil increased as the seeds developed. The values of these constants of ether extract were slightly lower in the seeds of *tirak*-affected plants than in the seeds of normal plants. The acid value of the extract was found to decrease as the seeds developed indicating a decrease in the free fatty acids. The ether extract of the seeds of *tirak*-affected plants showed slightly higher amounts of free fatty acids than the ether extract of seeds of normal plants.

TABLE I

Analysis of the oil from the seeds at different stages of growth

Age of bolls	Per cent oil	Iodine value	Saponification value	Acid value	Melting point °C.	Refractive index
(a) *Seeds from normal soil*						
7 days	1·33	36·45	155·20	56·40	52·0	1·485
14 days	1·31	34·86	158·80	57·05	50·5	1·485
21 days	1·34	37·05	157·60	55·92	51·0	1·485
28 days	6·16	85·70	179·30	31·37	7·0	1·475
35 days	15·23	96·22	183·20	18·64	3·5	1·474
42 days	21·17	102·50	189·50	8·74	2·2	1·474
49 days	23·96	108·40	193·40	2·55	2·0	1·474
56 days	24·59	109·55	194·70	0·45	2·1	1·473
(b) *Seeds from saline soil*						
7 days	1·33	37·81	151·80	54·02	51·0	1·486
14 days	1·36	35·31	156·60	52·42	51·5	1·485
21 days	4·81	62·88	170·50	38·93	10·0	1·476
28 days	9·61	83·38	177·10	29·16	9.0	1·475
35 days	11·81	92·25	182·50	17·48	3·5	1·474
42 days	12·38	96·30	185·70	10·51	2·8	1·474
49 days	12·41	101·75	186·20	7·64	2·5	1·474
56 days	12·67	101·20	187·80	5·45	2·4	1·474
(c) *Seeds from sandy soil*						
7 days	1·28	36·65	153·80	54·43	50·4	1·486
14 days	1·35	35·27	158·50	55·40	51·0	1·485
21 days	1·31	38·72	157·30	54·15	50·0	1·485
28 days	6·01	82·62	174·60	32·28	10·0	1·475
35 days	9·42	91·26	182·40	19·11	4·0	1·475
42 days	9·98	95·50	183·10	11·64	2·5	1·474
49 days	10·34	100·82	186·60	8·65	2·3	1·474
56 days	10·18	100·20	188·40	6·86	2·2	1·474

Thus except for minor differences in the different constants of oil, the nature of the oil formed in normal and *tirak*-affected plants appeared to be the same.

The reducing sugars, disaccharides, starch, and oil contents of the seeds from normal and *tirak*-affected plants are given in Fig. 3. The most noticeable feature was the fall in carbohydrates and a rise in oil content as the seeds matured. The reducing sugars and starch were present in larger amounts than disaccharides which were present in very small amounts.

The carbohydrate analysis of the carpels (Fig. 4)showed that reducing sugars were present in largest amounts. They showed a rise in the first two weeks after which they declined rapidly. The starch and disaccharides showed a decline at later stage.

Fig. 3. Percentage carbohydrates and oil in the 4F developing seeds of normal and *tirak*-affected plan's

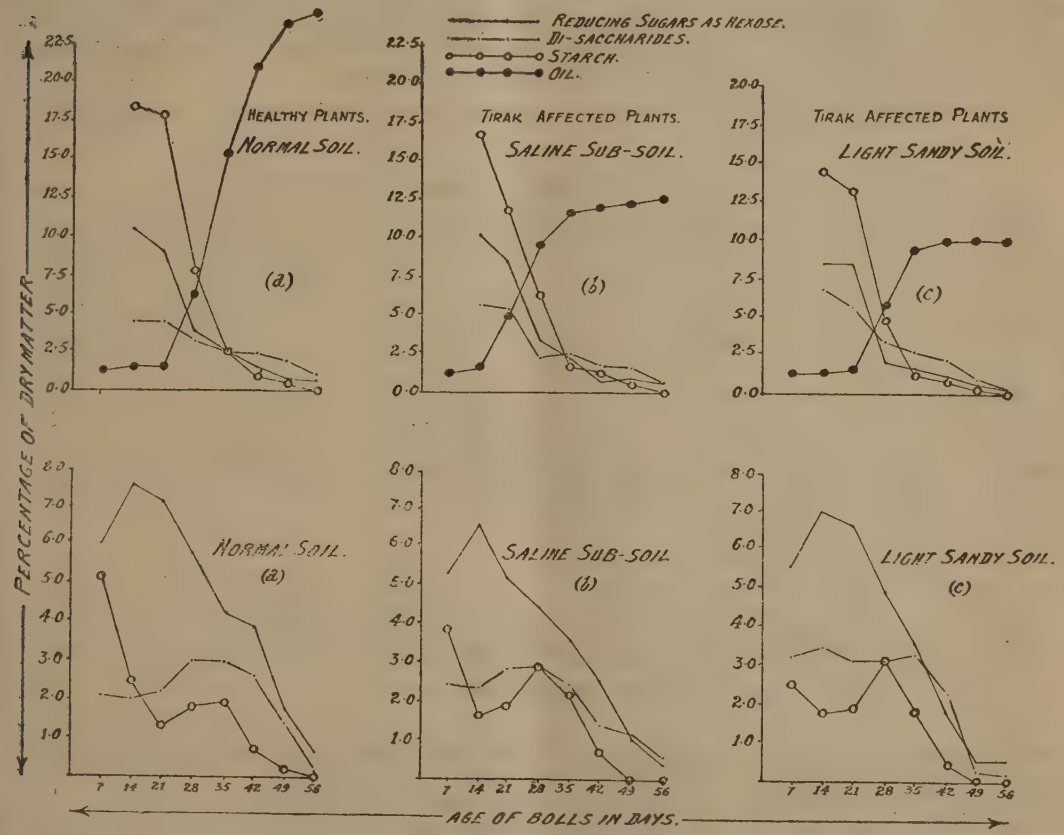


Fig. 4. Percentage carbohydrates in the developing carpels of normal and *tirak*-affected 4 F plants

Carbohydrates of lint

The lint from bolls of *tirak*-affected plants is known to be weak. The fibres easily break and consequently they are considered immature. As fibre strength is an economically important character, chemical nature of lint from normal and *tirak*-affected plants was determind.

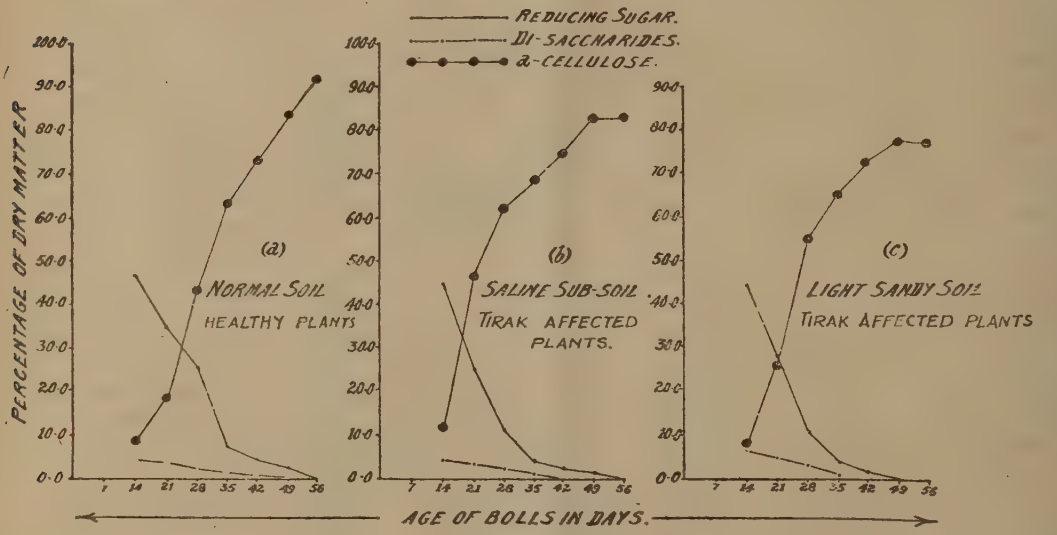
Hawkins and Serviss [1930] studied the development of cotton fibre in the Pima and Acala varieties of cotton and found that the elongation of the fibre was nearly complete in the first three to four weeks of boll development and the thickening of the fibre occurred during the remaining period. The development of lint in relation to soil coditions was studied by Sturkie [1934] and he concluded that the soil moisture was an important factor that influenced the maturity of fibres in cotton plant. When the available soil moisture was low, it produced a weak and short fibre. Hawkins [1931] also found that high concentration of soil alkali and comparatively low supply of soil moisture produced high percentage of immature seeds and fibres. These findings are in conformity with the

findings of this investigation as on soil with saline subsoils *tirak* occurred on account of unavailability of moisture. The biochemistry of cotton fibre at different stages of growth had also been studied by Jack and Forest [1940]. They found that the young fibre contained large quantities of reducing sugars relative to the mass of the crude fibre and there was a progressive reduction in the reducing sugars during the period when the fibres began to grow in thickness.

The structure and constitution of cotton fibre has also been investigated by various workers like Denham [1923], Kerr [1937], Kerr and Anderson [1938] and Nickerson [1940].

The carbohydrate analysis of the lint showed that reducing sugars were present in largest quantities in early stages. Fifty per cent of the dry weight of lint in the second week of development consisted of reducing sugars while disaccharides were present only in very small amounts. There was a progressive decline in reducing sugars of lint as it matured and it was almost nil in the fully mature fibres (Fig. 5). No differences were found between the carbohydrate contents of lint from *tirak*-affected and normal plants.

Fig. 5. Percentage carbohydrates and alpha cellulose in the 4F normal and *tirak*-affected developing lint



The progressive decline in reducing sugars was accompanied by an increase in the cellulose content of the lint (Fig. 5 a, b, c). Thus there was clear evidence that callulose was formed at the expense of reducing sugars. The molecules of cellulose are known to consist of a number of anhydrous glucose molecules and its synthesis from reducing sugars in the case of lint can be regarded as highly probable.

Further analysis of cellulose of the lint revealed that it was mostly composed of α-cellulose. β-cellulose and 8-cellulose were found in very small qunatities. The lint of normal plants contained about 91 per cent of α-cellulose on dry weight basis, while the lint of *tirak*-affected plants from soils with saline subsoil and light sandy soils contained 82 and 76 per cent of α-cellulose respectively at maturity (Fig. 5 a, b, c).

Technological study of lint

The lint of *tirak*-affected plants, although weak in strength, is not reduced in length. The decrease in the cellulose contents of the lint in *tirak*-affected plants may, therefore, be due to a decrease in its growth in thickness as the secondary thickening of the fibres generally occur as a result of deposition of fresh cellulose layers on the primary cell wall. The cellulose content of the lint from *tirak*-affected plants was found to be lower than that from normal plants. This conclusion was further supported by the technological tests carried out on the lint from normal and *tirak*-affected plants at the laboratory of the Cotton Botanist, Mirpurkhas.

TABLE II

Technological properties of lint from normal and tirak*-affected plants*

Lint samples collected from	Mean fibre weight 10-6 gm.	Mean length in inches	Maturity count (per cent)		
			Mature fibres	Half mature fibres	Immature fibres
1. Normal soil	0·172	0·79	76	10	14
2. Saline sub soil	0·128	0·71	48	12	40
3. Light sandy soil ..	0·114	0·71	38	18	44

There was no appreciable difference in lint length, but there was marked difference in the fibre weight per unit length. The fibre from normal plants weighed more per unit length than the fibre from *tirak*-affected plants. Thus the conclusion that the lint of *tirak*-affected plants did not grow in thickness by secondary deposition of cellulose to the same extent as it did in the case of normal plants was again confirmed. This was also clear from the maturity counts given in the same Table. The lint of *tirak*-affected plants was found to contain a higher proportion of immature fibres than the lint of normal plants.

CONCLUSIONS

The protein metabolism of the bolls of *tirak*-affected plants appeared to deviate from the normal course from the fifth week and the synthesis of proteins in the seeds did not occur in the former in the last three weeks of development

There was an increase in protein nitrogen and a decrease in soluble nitrogen as the seeds developed indicating that protein nitrogen was synthesized from the soluble forms of organic nitrogen. The primary synthesis of proteins generally occurs in the leaves. The proteins hydrolize afterwards into soluble forms of organic nitrogen and travel to different parts of the plants. In this case they travelled from the leaves to the developing bolls. This conclusion was also supported by the fact that percentage distribution of total nitrogen declined in the leaves at the fruiting stage while it increased in the bolls [Dastur and Ahad, 1941].

The concentration of potash was also found to decrease in the leaves at the fruiting stage and in the carpels from the fifth week of development in *tirak*-affected plants while it continued to rise in the carpels of normal bolls. Thus lack of potash probably appeared to be related to the cessation of protein synthesis in *tirak*-affected plants and whatever small amounts of soluble forms of organic nitrogen reached the bolls they remained unconverted into proteins and consequently accumulation of soluble nitrogen occurred in the carpels and seeds, mostly in the forms of amides and amino acids. Richards and Templeman [1936] pointed out that potassium in some manner was essential for the maintenance of the protoplasmic complex, and in its absence protoplasm did not function normally, and consequently further protein synthesis was checked and accumulation of simpler nitrogen fractions occurred throughout the plant. The results discusssed above showed somewhat similar trends.

It was already shown [Dasur and Ahad, 1944] that the bolls from *tirak*-affecteed plants did not increase in dry weight from the fifth week of development, while in the case of normal bolls the increase in the dry weight continued up to the last stage of development. Thus when protein synthesis stopped the growth of *tirak* affected bolls had also ceased.

The results described above definitely indicated that proteins and oil in seeds and cellulose in lint were formed from carbohydrates. The reducing sugars appeared to be the main carbohydrate utilized in the formation of protein and oil in seeds and of cellulose of lint as this kind of sugar declined in carpels, seed and lint as development proceeded. The starch and disaccharides found in the carpels and seeds may be regarded as temporary storage products resynthesized from reducing sugars. These higher forms of carbohydrates appeared to be reconverted into reducing sugars as the latter

were being utilized in synthesis of protein and oil.

The cellulose content of the lint from normal plants was higher than that of the lint from *tirak*-affected plants and that was due to a decrease in the secondary thickening of the fibre in the latter. Consequently the lint from *tirak*-affected plants was weak in strength.

Summary

The fromation of proteins in bolls of *tirak*-affected cotton plants ceased from the fifth week of development while proteins continued to be synthesized up to the eighth week of boll development in the normal plants. The cessation in protein synthesis in bolls of *tirak*-affected plants was accompanied by an accumulation of soluble froms of non-protein nitrogen from the same stage of development. These froms of nitrogen, on the other hand, were found to decline continuously in the bolls of normal plants. A disturbance in the synthesis of proteins in the bolls of *tirak*-affected plants was therefore clearly indicated and the accumulation of soluble forms of nitrogen could be linked up with a deficiency of potash in the leaves and carpels. The decreased rate of protein formation in bolls of *tirak*-affected plants was associated with a decrease in dry matter of the bolls. Thus the growth of bolls ceased at an earlier stage in the *tirak*-affected plants as compared with normal plants.

The corbohydrate analysis of bolls did not show any differences between the normal and *tirak*-affected plants though a decrease in the oil content was found to be a feature of the bolls of the latter. Thus carbohydrate supply did not appear to be responsible for either decreased protein or oil synthesis in the bolls of *tirak*-affected plants. Potash deficiency [Dastur and Ahad, 1944], therefore, appeared to be the primary cause that led to the development of immature seeds in *tirak*-affected plants.

The anslysis of lint showed that cellulose was formed at the expenses of reducing sugars. The main differences between normal and *tirak*-affected bolls were found to be in the cellulose content of the lint, the percentage of the cellulose being much higher in the lint of the former than in the lint of the latter. The decreased cellulose content appears to be associated with a decrease in the secondary thickening of the fibre as the lint length was found to be nearly the same in the normal as well as *tirak*-affected plants.

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STUDIES ON STORED GRAIN PESTS IN THE PUNJAB
VI. BIOLOGY OF *TROGODERMA GRANARIUM* EVERTS*

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(With one text-figure)

NINETEEN insects have so far been recorded as infesting food grains in the Punjab [Rahman, 1942] and out of these 'Khapra' (*Trogoderma granarium* Everts: *T. Khapra* Arr.) is the most abundant and destructive in our commercial centres of wheat production. Barnes and Grove [1916] had worked out the biology of this pest in broad outlines only. In order to subjugate a pest completely and cheaply, a thorough knowledge of its biology is essential. Hence observations on the biology of this important pest were taken up seriously in 1939 and the results are presented in this paper.

I. Observations on the reactions of Dermestid beetle, *Trogoderma Khapra* Arr. to light. *Indian J. Ent.* **1**, 57-63 (1939)

II. Insect pests of stored grains in the Punjab and their control. *Indian J. agric. Sci.* **12**, 564-87 (1942)

III. Biology of *Bruchus analis* Fab. and *B. chinensis* Linn. (Bruchidae : Coleoptera.) in the Punjab. *Indian J. agric. Sci.* **12**, 851-64 (1942)

IV. Save stored grain from insects. *Indian Fmg.* **4**, 18-20 (1943)

V. Fighting 'Khapra' in the Punjab. *Indian Fmg.* **5**, 272-5 (1944)

DISTRIBUTION

Trogoderma granarium Everts is a native of India. It has been carried to the following countries mostly on wheat and barley: Britain, Germany, Holland, Korea, Japan, Odessa, North America and Rotterdom. In India, it is found in U. P., Central Provinces and Berar, Sind, North West Frontier Province, Gwaliar and the Punjab. In the Punjab, it is confined to the plains where it causes the greatest damage to wheat particularly in the hotter and drier parts, the areas of its greatest destructiveness being the canal colonies [Rahman, 1942].

FOOD

T. granarium is a very serious pest af wheat. In addition to the food mentioned by Rahman [1942], it has also been recorded from bran in

the Punjab, malt in Germany and England, pulses, oats and rye in Germany. Wheat, however, is its principal and most favoured food.

Life history

Precopulation period. According to Nakayama [1933], the adults mate 2-3 days after emergence; we, however, found them to mate immediately after emergence.

Preoviposition period. According to Voelkel [1924] a female started laying eggs 5-6 days (at 25°C.) after mating while according to Nakayama [1933] it oviposited immediately after mating. We found the duration of the preoviposition period to depend upon the time of the year: it lasted for 2-4 days in April, 1-2 days during May-September and 2-5 days in October.

Oviposition. Barnes and Grove [1916] recorded the adults and the eggs during April-September, but we have found that the females from the over-wintered grubs started egg laying in the second week of April and their succeeding generations continue to oviposit up to the end of October in the laboratory and up to the end of November in the heavily infested stores. According to Barnes and Grove [1916] and Mason [1921], the eggs are laid in the groove or some other portion of the surface of grain, while Rahman [1942] and others assert that they are laid among the grain generally singly, rarely 2-5 together. Barnes and Grove [1916], Voelkel [1924], Mason [1921], Morison [1925] and Nakayama [1932] maintained that a single female laid 35-40, 65 at 30°C., 35-40, 50 and 20-30 eggs respectively in her life time, while Rahman [1942] stated that in its life time a female laid 85 eggs in 7 days at the rate of 1-26 eggs per day. During our present investigations, however, we have found that there is a considerable variation in the amount of oviposition among the individual females in all the months and a female has been observed to lay 4-89 eggs in 1-8 days at the rate of 1-55 eggs per day. Maximum amount of oviposition recorded during these investigations was about double, i.e. 89 as compared to that recorded by Barnes and Grove [1916], i.e. 41. Voelkel [1924], recorded 126 to be the maximum number of eggs laid by a single female at 30°C. A female laid the highest number of eggs during April-May and least during October. Table I gives the oviposition period, total number of eggs laid by a female and its daily rate of oviposition for each month from April to October.

Table I

Oviposition record of T. granarium *Everts*

Month	Total Number of eggs laid			No. of eggs laid daily			Oviposition period (in days)		
	Max.	Min.	Aver.	Max.	Min.	Aver.	Max.	Min.	Aver.
April	89	7	52.2	55	1	8.7	8	2	6.0
May	88	13	52.7	44	2	12.0	7	2	4.4
June	85	13	30.4	22	1	7.5	6	2	4.1
July	47	4	23.7	18	1	6.8	5	1	3.5
August	60	12	32.0	26	2	7.8	7	1	4.1
September	52	9	31.0	24	1	5.7	6	2	4.2
October	28	4	15.9	9	1	4.5	5	2	3.6

Egg. It measures 0.11 mm. in length and 0.03 mm. in its greatest diameter.

Incubation period. Barnes and Grove [1916], Mason [1921], Morison [1925], Nakayama [1932] and Rahman [1942] have stated that the egg stage occupied 5-7, 6-7, 5-9at 30°C, 6-12 and 5-10 days respectively. We have found the incubation period to vary with the season; eggs laid in April hatched in 5-9 days, those laid during May-August hatched in 3-6 days while those oviposited in September and October took 5-10 days to hatch (Table II). This shows that contrary to the observations made by Barnes and Grove [1916], there is an extensive variation in the duration of the egg stage during different parts of the year, i. e. in June egg stage occupied about double the period (Table II) than that taken by it in April and October.

TABLE II

Incubation period of T. granrium *Everts*

Month	No. of observations	Incubation period (in days)		
		Max.	Min.	Aver.
April ..	180	9	5	7.1
May ..	477	6	4	5.4
June ..	140	5	3	4.4
July ..	192	6	4	4.6
August ..	366	6	3	4.8
September ..	264	8	5	6.2
October ..	68	10	6	6.7

Viability of eggs. Viability of the eggs was found to be 48.6 per cent in April, 41.5 per cent in June, 60.3-66 per cent in May and August, 51.95-58.4 per cent in July and October and 86.8 per cent (i.e. highest) in September.

Larval stage. Nakayama [1932] has recorded the larvel stage to occupy 317-351 days while according to Rahman [1942] the male and female larvae are full-fed in 19-28 and 20-37 days respectively. During our present investigations we found a male larva to be full-fed in 16-53 and a female larva in 20-63 days (Table III) and during this period they moulted 3-4 and 4-6 times respectively as against 4 and 6 recorded by Barnes and Grove [1916] respectively.

TABLE III

Duration of the larvel stage of T. granarium *Everts*

Month	Male larvae				Female larvae			
	Number of observations	Duration in days			Number of observations	Duration in days		
		Max.	Min.	Aver.		Max.	Min.	Aver.
April-May ..	47	53	16	37.9	59	63	25	40.9
June ..	26	34	18	24.0	36	43	23	27.8
July ..	45	26	17	21.5	33	37	20	26.8
August ..	28	27	16	18.5	21	36	20	24.5
September ..	24	22	18	19.8	14	32	25	28.5

Overwintering larvae. Time of their entering into hibernation depended upon whether the larvae were feeding in the laboratory or in the godown. Those feeding in the laboratory started entering hibernation on 9 August while in the case of those in the godown hibernation began in the end of November. A few typical cases of the duration of overwintered larvae are given in Table IV.

TABLE IV

Duration of the overwintered larvae

Date of hatching	Date of pupation	Duration in days
9 August 1941 ..	3 May 1942 ..	267
16 August 1941 ..	30 May 1942 ..	287
30 August 1941 ..	9 April 1942 ..	222
22 September 1941 ..	18 April 1942 ..	208
1 October 1941 ..	13 April 1942 ..	194
15 October 1941 ..	7 May 1942 ..	214
16 October 1941 ..	5 June 1942 ..	171
26 October 1941 ..	1 July 1942 ..	186

Pupal stage. According to Mason [1921], the larvae pupated inside the malt grain (which it never leaves until it eats up all the endosperm), while according to Rahman [1942] pupation takes place in the last larval skin among the grains. We found the pupae to abound usually in the top layers of the stored wheat. According to Nakayama [1932], the pupal stage was completed in 6-17 days, while according to Rahman [1942] it occupied 4-6 days. We, however, found the pupal stage to occupy 3-6 and 3-8 days in case of male and female pupae respectively.

Longevity of the adults. According to Barnes and Grove [1916] and Voelkel [1924] the adults before emergence remain in the last larval skin for 2-3 days and from several hours to 10 days respectively. We, however, found this period to last for 15-78 hours. Barnes and Grove [1916] have only recorded the maximum longevity of the adults (10 days) whereas Mason [1921] has found the adults to live from a few to 10 days. We have worked out the longevity of the female and male adults separately in different months of the year which is presented in Table V.

TABLE V

Longevity of adults in different months

Month	Males (in days)			Females (in days)		
	Max.	Min.	Aver.	Max.	Min.	Aver.
April	14	3	10.9	13	7	10.8
May	10	4	7.2	15	5	7.2
June	6	3	4.9	14	5	7.4
July	7	4	5.4	7	4	5.7
August	10	4	6.4	14	5	7.2
September	11	4	8.0	11	5	8.2
October	11	5	8.9	13	7	9.8

It will be observed from Table V that both the males and females live the longest during April and shortest during June and July respectively.

SEASONAL HISTORY AND NUMBER OF GENERATIONS

According to Barnes and Grove [1916], the pest remains active from April to September and in a completely dorment condition from Octotober to March. We, however, have found that the pest remains active from mid-March to October in the laboratory and up to the end of November or even later in godowns, where wheat is stocked in bulk and the infestation is very high. Further, it was observed in the laboratory that some of the larvae which hatched from the eggs laid on 9 August 1941 entered into hibernation, while the remaining larvae completed their growth and emerged as adults by September. This went on up to the 15 August 1941, after which date all the larvae which hatched out of the eggs entered into hibernation. Thus in the laboratory *T. granarium* started hibernation as larvae from 15 August. The seasonal activity of the pest is given below.

January to mid-March. Only hibernating larvae present. Activity nil.

Mid March to mid-April. Larvae resume activity.

Mid April to end of April. Pupation starts. Adults appear and lay eggs. Larvae and pupae also present.

May to August. All stages of the pest present, damage maximum. In the laboratory some of the larvae hatching in the first week of August enter into hibernation where as all those which hatched after 15 August hibernated.

September. All stages present but pupae and adults comparatively less. Pest activity shows distinct decline.

October. Larvae preponderate over other stages. Activity greatly reduced.

November-December. Only larvae present. Activity particularly at stand still.

According to Barnes and Grove [1916] and Nakayama [1933], *T. granarium* has four and two distinct generations a year respectively, but we have found the pest to pass through 4-5 overlapping generations during the year (Fig. 1).

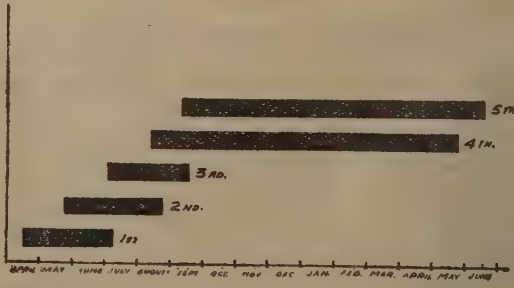

FIG. 1. NUMBER OF GENERATIONS OF *T. granarium* EVERYS.

SEX RATIO IN DIFFERENT GENERATIONS

The ratio of the males and the females in different generations was almost at par except in the fifth generation, when the females predominated (Table VI).

VIABILITY OF DIFFFRENT STAGES

Viability of eggs was usually low in all the generations except fourth, when it was 86·8 per cent. Viability of the larvae was fairly high throughout their period of activity. Mortality among pupae was negligible. Results of our observations on this point are presented in Table VII.

TABLE VI

Sex ratio of T. granarium *Everts in different generations*

No. of generations	Total No. of adults counted	No. of males	No. of females	Sex ratio	
				Male	Female
1st	245	119	126	48·2	51·8
2nd	103	53	50	51·3	48·7
3rd	145	75	70	51·7	48·3
4th	244	117	127	48·0	52·0
5th	40	16	24	40·0	60·0

TABLE VII

Viability of different stages of T. granarium *Everts in different generations*

Generations	Eggs laid	Eggs hatched	Larvae pupated	Adults emerged	Percentage of viability		
1st	713	364	335	305	51·5	92·0	91·3
2nd	337	140	110	107	41·5	78·6	97·3
3rd	370	192	149	145	51·9	77·6	97·9
4th	304	264	244	244	86·8	92·4	100·0
5th	77	45	40	40	58·5	88·8	100 0

DEVELOPMENT OF LARVAE ON VARIOUS FOODS

Development of the pest was studied during June 1943 on the following nine food stuffs: Wheat, barley, *bajra* (*Penuisetum typhoideum*), *jowar* (*Andropogon sorghum*), rice, *pista* (*Pistacea vera*), gram, and walnut. Twenty-six newly hatched larvae were confined on each food stuff in small petri dishes and the developmental periods of the male and female larvae together with their viability were noted. Results are tabulated below:

It will be observed from Table VIII that the larval duration was shorter on wheat, *bajra*, maize, *jowar*, and rice, and comparatively longer on barley and gram and longest on *pista* and walnut, while percentage of viability was highest on rice and lowest on *jowar*.

Amount of food consumed by the larvae

A single wheat grain of known weight was given to each newly hatched larva in a petri dish and as soon as it changed into a pupa, the grain was weighed again and the total and daily amount of food consumed by the female and male larvae was worked out seperately. Results are given in Table IX.

Table VIII

Comparative rate of development and the percentage of larvae successfully completing their growth on different foods

Food stuff	Duration of the larval stage (in days)						Percentage of viability of the larvae
	Male larvae			Female larvae			
	Max.	Min.	Aver.	Max.	Min.	Aver.	
Wheat ..	42	17	26·0	47	26	35·2	73·0
Barley ..	49	22	32·8	51	28	40·1	80·7
Gram ..	40	34	35·8	52	32	42·0	61·5
Bajra ..	28	21	24·8	34	26	29·4	61·5
Maize ..	38	21	25·6	46	26	39·9	76·9
Jowar ..	31	22	25·0	34	24	29·2	34·6
Rice ..	33	22	28·0	46	26	37·0	88·4
Pista ..	50	34	38·4	52	33	43·5	57·6
Walnut ..	45	31	37·1	52	34	43·1	57·6

Table IX

Amount in mg. of food consumed by the larvae

Month	Male larva						Female larva					
	Daily amount of food consumed			Total food consumed			Daily amount of food consumed			Total food consumed		
	Max.	Min.	Aver.	Max.	Min.	Aver.	Max.	Min.	Aver.	Max.	Min.	Aver.
June ..	0·444	0·074	0·173	5·0	1·5	3·3	0·561	0·136	0·401	14·8	5·0	10·0
July ..	0·600	0·083	0·293	10·0	1·5	5·1	0·770	0·269	0·520	17·0	7·4	11 7

It will be observed from Table IX that the female larva consumed nearly double the quanity of food as compared to the male larvae.

Penetration in a heap of wheat

Barnes and Grove [1916] observed that the insect mostly confines itself to the top 10-12 in. layer of grain in a heap but we have observed the insect to be almost equally serious up to 2.5 ft. depth from the top as given in Table X.

Table X

Percentage of attack in the upper 2½ ft. column of grain

Column of grain from the top	Percentage of attack
0-6 in.	59·6
6-12 in.	52·4
12-18 in.	58·0
18-24 in.	54·0
24-30 in.	54·0

As we go deeper into the heap the attack goes on adiminishing and at about 6 ft. it is negligible. Along the walls and in the corners the insect may penetrate as deep as 9 ft.

Heating of the grain

Presence of *T. granarium* among the grain causes heating. In a laboratory experiment conducted during June, July and early August, it was observed that the presence of 4000 larvae in a 5000 c.c. bottle full of wheat raised the temperature of the grain by 2-4°F. over and above the room temperatute and by 1-1·5°F. over and above the healthy wheat in a similar bottle. It was also noticed that at the time of pupation and emergence of adults, heating was not appreciable. So the extent of heating naturally depends upon the population of insect particularly the larvae. Observations carried out in big stores at different centres in the province, besides confirming the above finding, brought to light another important fact. As a result of this heating, the period of activity of this pest was extended and the pest was found to be actively feeding and breeding even up to the end of November since temperature conditions in the godown were quite favourable for its multiplication, i.e. 83°-105°F.

This shows that heating of wheat is an index of 'Khapra' activity and wheat in the godown that is hot to touch should be rejected. This important observation should be made use of by all Government Departments which are required to handle wheat while making purchases. The stockists on the other hand should take care to keep the godowns as cool as possible by providing proper circulation of air in them

Extent of damage

Extent of damage is calculated on entirely different basis by the seedsmen and the merchants. To a seedsman, percentage of damaged grain in a sample is the true index of the extent of damage whereas to the general trade, the total amount of loss in weight as a result of insect attack matters the most. Observations so far carried out in different parts of the province have shown that the extent of damage caused by this insect depends upon (i) initial infestation of the store; (ii) infestation in the adjoining store; (iii) condition of stock to be stored; (iv) time of the year when the grain is stocked; (v) type of storage receptacle; (vi) method of storage; (vii) extent of ventilation in the store; and (viii) period of storage. Data so far collected from the point of view of seedsmen and the merchants are given below.

(a) *From the point of view of seedsmen*

In a single storing season *T. granarium*, on an average, has been observed to damage the grain to the extent of 5.9 to 32.8 per cent with a maximum of 73.0 per cent.

(b) *From the point of view of trade*

In order to judge the destructive potentialities of 'khapra' alone, some stores were selected in which wheat was attacked by this insect only and was stored from July to November. Results are given in Table XI.

Table XI

Percentage of loss in weight in a single storing-season

Amount of wheat stored	Amount of wheat recovered	Percentage of loss in weight
2,000 maunds ..	1,955 maunds ..	2·25
365 „ ..	345 „ ..	5·47
805 „ ..	775 „ ..	3·72

Summary

Trogoderma granarium Everts. is a serious pest of stored wheat and is distributed all over Northern India. It is active from mid-March to October, but in the heavily infested godowns where the temperature rises due to insect activity, it has been observed breeding even up to the end of November.

A female lays 4-89 eggs in 1-8 days at the rate of 1-55 eggs per day. Incubation period lasts for 3-10 days, larval stage occupies 16-53 days in case of male larvae and 20-63 days in case of female larvae, pupal stage being completed in 3-8 days and the adults live for 3-15 days depending upon the season. It passes through 4-5 generations in a year.

Sex ratio and viability of different stages in different generations is given. Comparative development of the insect has been studied on new different foods. Larval duration is found to be shorter on wheat, *bajra*, maize, *jowar*, and rice and the percentage of the viability of the larvae is highest on rice and lowest on *jowar*. The daily consumption of food by a female larva varies from 0.136 mg. to 0·77 mg. which is double than that of the male larva. Incidence

of the pest at different depths in a heap is discussed. In a single storing season, the extent of damage caused by this insect from the point of view of seedsmen and trade has been worked out at 5·9-32·5 per cent and 2·25-5·47 per cent respectively.

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COLLAR ROT OF PIGEON-PEA CAUSED BY *PYTHIUM APHANIDERMATUM* (EDSON) FITZ.

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IN July 1943, a few wilted plants of pigeon-pea (*Cajanus cajan*) variety U.P. 132, were received for examination from the Agricultural Section of the Imperial Agricultural Research Institute, New Delhi. Transverse sections revealed the presence of fungal hyphae, especially in the xylem vessels. Isolations yielded a species of *Pythium*, besides *Macrophomina phaseoli* (Maubl.) Ashby, and a *Fusarium* Sp. different from *Fusarium udum* Butler, which causes the *Fusarium* wilt of this crop.

Isolations were again tried from speciemens collected from the same plot in August and September and these largely yielded *Pythium* Sp. Some of the isolations from plants collected in September, yielded *Corticium Rolfsii* (Sacc.) Curzi.

The *Pythium* when grown on potato dextrose agar produced abundant mycelium measuring 2·4-8·2μ diam. It formed lobulate sporangia and swollen antheridia. The oogonia measured 21 (14-34) μ and the oospores 17 (12-29) μ. The fungus agrees closely with *Pythium Butleri* Subr. and *P. aphanidermatum* (Eds.) Fitz. These two fungi were considered by Carpenter [1921] to be identical and Mitra and Subramaniam [1928] regarded *P. Butleri* as a 'strain' of *P. aphanidermatum* producing different symptoms of foot rot on papaya and having larger oogonia and oospores than the typical forms. Drechsler [1934] who studied nearly 100 isolates from various plants considered that there are two distinct species, *P. Butleri* having somewhat larger oogonia and oospores than *P. aphanidermatum*. The measurements given by the several workers are as follows:

Species	*Oogonia*	*Oospores*	*Authority*
P. Butleri Subr.	26 (18-33) μ	21 (13.5-25.3) μ	Subramaniam [1919]
„ „	27	22.5	Drechsler [1934]
P. aphanidermatum (Eds.) Fitz.	2-272	17-19	Edson [1915]
„ „ „ „	19.8-28.6	14.3-20.9	Mitra and Subramaniam [1928]
„ „ „ „	22	17.5	Drechsler [1934]
Pigeon-pea isolate	21 (14-34)	17 (12-28)	Author

It will be noted that the pigeon-pea isolate has average measurements agreeing closely with *P. aphanidermatum*, but the range agrees with *P. Butleri*. Drechsler [1934] gives no detailed statistical analysis and one is led to believe that the differences in average measurements may not be significant. Whether in the broader meaning of Carpenter [1921], Mitra and Subramaniam [1928], or in the narrower sense of Drechsler [1934], however, the pigeon pea fungus must be regarded as *Pythium aphanidermatum* (Eds.) Fitz.

Experiments to test the pathogenicity of the fungus were made. In the pot experiments,

germination failed when the fungus was applied at the sowing time but when applied to the stem just above soil level, a few days after sowing, it caused a drying of the leaves and the tender shoots, and some plants dried up at the collar region. The fungus was reisolated from these plants.

Observations in the pots from where diseased specimens were obtained, showed that scattered plants had wilted over a large are, growing at a low-lying place in wet soil. The soil is such that it retains water at the upper surface for a considerable time.

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A NOTE ON THE DETERMINATION OF ORGANIC NITROGEN IN SOILS

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THE determination of organic nitrogen in soils is of great importance in all studies on the nitrogen status of soils. The method commonly used is to digest the soil with strong sulphuric acid in the presence of anhydrous potassium sulphate and copper sulphate and to distil off ammonia with caustic soda and arrest it in standard acid.

Bal [1925], while working on black cotton soils of the Central Provinces, found that a higher figure for nitrogen was obtained by 'Wet' digestion method than by the original 'Dry' digestion method. This was later confirmed by Sreenivasan [1932].

In our recent studies on the losses of nitrogen from soils it was considered necessary to standardize the method for the determination of organic nitrogen. For this purpose a trial experiment was conducted with two samples of soil, a sandy loam and a clay loam soil, and nitrogen determined by the original 'Dry' digestion method and the modified or the 'Wet' digestion method with 1:1 acid. The results obtained are given in Table I.

TABLE I

Mg. N per 100 gm. of soil

Soil	Dry digestion	Wet digestion
Sandy loam ..	28.7	29.4
	28.7	29.4
Clay loam ..	78.4	70.0
	77.0	71.4

It will be seen from Table I that in sandy loam soil the figure for organic nitrogen was practically the same by both the methods. In clay loam soil, however, the 'Dry' digestion method gave higher results by about 7 mg. of nitrogen. The determinations were repeated with the same results.

The difference in results by the two methods could be attributed either to incomplete digestion of certain forms of nitrogen by the 'Wet' digestion method, which is unlikely and contrary to the existing evidence or due to the reduction of nitric nitrogen in the 'Dry' digestion method. In order to test the latter point both the soil samples used in the previous experiment were separately treated with potassium nitrate solution to supply 50 mg. nitric nitrogen per 100 gm. of soil. These samples were air dried, and the nitrogen determined by both the methods. The results were as shown in Table II.

TABLE II

Mg. N per 100 gm of soil

Soil	Method of digestion	Nitric N added	Organic N determined	Nitric N included
Sandy loam..	Dry	Nil	28·70	—
Sandy loam..	Dry	50	38·50	9·80
Sandy loam..	Wet	Nil	29·40	—
Sandy loam..	Wet	50	28·70	Nil
Clay loam ..	Dry	Nil	78·4	—
Clay loam ..	Dry	50	92·4	14·0
Clay loam ..	Wet	Nil	70·0	—
Clay loam ..	Wet	50	71·4	1·4

From Table II it will be seen that in both the soils a part of the nitric nitrogen added was reduced by the 'Dry' digestion method and that the reduction was greater in the clay loam soil than in the sandy one. On the above evidence it may be concluded that the higher results originally obtained for nitrogen in the untreated clay loam soil were due to the reduction of a part of the original nitric nitrogen (12 mg.) present in the soil.

The experiment was repeated with some other typical soils from different localities. The soils were treated with potassium nitrate at 50 mg. nitrogen per 100 gm. of the soil, and nitrogen estimated by both the methods. The results (Table III) confirmed the above finding, viz. that a part of nitric nitrogen is reduced by dry digestion. The reduction is comparatively greater in the Palampur soil which is rich in organic matter.

TABLE III

Mg. nitrogen per 100 gm. of soil

Soil	Percentage		Method of digestion		Nitric N included
	Clay	Organic matter	'Dry'	'Wet'	
Palampur ..	35	1.5	199.6	173.6	26.0
Dhundi estate	46	0.3	100.1	94.5	5.6
Montgomery	20	0.2	55.3	47.6	7.7
Sargodha ..	24	0.3	57.4	46.2	11.2

In order to confirm the above results, another experiment was conducted as follows:

One hundred grams of the clay loam soil were shaken with 400 c.c. of distilled water for half an hour, transferred to a Buchner funnel and washed free of nitrates. The washed soil was air dried, sieved and organic nitrogen determined by both the methods. The results were as follows:

	Mg. N per 100 gm. soil
'Dry' digestion	69.3
	69.3
'Wet' digestion	70.7
	70.7

From these results also it becomes clear that higher results for organic nitrogen obtained previously by the 'Dry' digestion method were due to the reduction of nitric nitrogen.

For further verification of the results, the digestion of clay loam soil (original sample) was conducted in a closed system. The evolved gases were slowly bubbled through soda and ferrous sulphate solutions. When the digestion was complete, purified air (free from ammonia and nitrous fumes) was aspirated for a few minutes. The contents of the absorption bottles were reduced with Devarda's alloy and nitrogen estimated. It was found that the gases from the 'Wet' digestion flask contained more nitrogen than those from the 'Dry' digestion flask (3.0 mg.) This showed that the oxides of nitrogen which are produced by the action of sulphuric acid on nitrates are partly fixed up in the course of the 'Dry' digestion.

CONCLUSION

From the foregoing it becomes clear that a part of the nitrate nitrogen is reduced in the 'Dry' digestion method and therefore the results obtained for organic nitrogen are higher. The explanation seems to be that the nitrates are readily decomposed by the action of sulphuric acid whether dilute or strong with the evolution of nitrous fumes. In the 'Dry' digestion method, by the simultaneous action of the concentrated sulphuric acid on organic matter of the soil, numerous compounds are formed, side by side with the nitrous fumes and these exercise a reducing action on the nitrous fumes. While in the 'Wet' digestion method the nitrous fumes are boiled off before the acid is sufficiently concentrated to elaborate reducing substances.

The apparent conclusion from these studies is that the usual dry digestion method of the determination of organic nitrogen in soils gives higher results if the soil is rich in nitrates and that the 'Wet' digestion method is preferable.

In our trials, since 'Dry' digestion brought about the reduction of a part of nitric nitrogen even in case of a sandy soil which was very poor in organic matter, it is likely that a similar effect would be noticeable in other soils as well.

There is a seeming contradiction between our results and those obtained by Bal [1925] and Sreenivasan [1932], but it vanishes when we remember that they got lower results by 'Dry' digestion due to the incomplete digestion of their soils. The error due to this was very likely big enough to mask the effect of nitrate reduction as observed by us.

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THE BIOLOGICAL DECOMPOSITION OF GREEN MANURES
I. CARBON-NITROGEN TRANSFORMATIONS DURING DECOMPOSITION

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INTRODUCTION

IN tropics, where animal manure is scarce, green manures form an essential feature in the system of crop husbandry employed in the growth of plantation crops. The maintenance of an adequate supply of organic matter in the soil carrying these crops depends largely on the frequent turning under of green manure crops.

Although green manuring offers a handy method in improving the organic matter status of soils yet it is highly complicated. Farming practice varies so much from place to place that success in extending the use of green manures depends first and foremost on an intimate knowledge of local conditions. The possibilities of green manuring, as of any other agricultural practice, will always vary from season to season. Such a tricky character of the practice of green manuring has been amply demonstrated by the failure of wheat and barley grown after mustard and tares in the famous Woburn experiments. A detailed account of these experiments is given by Crowther and Mann [1933].

The subject of decomposition of green manures has attracted the attention of several workers on account of its complicated character. Studies have been made by Tenny and Waksman [1929], Crowther and Mirchandani [1931], Mirchandani [1931] and Daji [1934], using soil as the medium. The results of all these workers point to the same conclusions, viz. (a) that the age and nature of green manure plants have an influence on the amount and rapidity of liberation of nutrients, particularly nitrogen in an available form; and (b) unless a crop is ready to avail itself of such rapidly available nitrogen as ammonia or nitrate, the latter may soon get leached out during winter-rains and some nitrogen may also be lost through volatilization.

As it is rather difficult to follow the changes in the soil because of the small quantities of nitrogen present for direct experiment, a parallel case was chosen where the biochemical decompositions are similar to those in the soil but the quantities of nitrogen are relatively large. Such a method has been successfully adopted by Rege [1927], Norman [1929] and Shrikhande [1933, 1], for the study of several factors involved in the decomposition of materials like straws. These workers have followed the changes in nitrogen with respect to loss of dry matter with materials of a wide carbon-nitrogen ratio, but such direct study has never been reported so far for materials naturally rich in protein. Moreover, Howard [1935] has lately been advocating the composting of green manures instead of their direct incorporation on tea estates of Ceylon. It was therefore thought desirable to imitate the process of composting in the laboratory under controlled conditions to see how far such a process compares with the age-long practice of green manuring. With this object in view the subject was followed up in considerable detail by studying the carbon-nitrogen changes in composts obtained and their respective hydrogen peroxide and water extracted residues as outlined below.

EXPERIMENTAL

A number of green manures with other vegetable materials used for composting on tea estates in Ceylon was rotted in presence of mixed natural flora for 35 days at room temperature of about 30°C., with the following changes in the nitrogen supply:

(a) Plant materials independently of any external source of nitrogen.

(b) Plant materials in presence of ammonium sulphate.

(c) Plant materials in presence of sodium nitrate.

(d) Comparitive tests on nitrification.

Original plant materials and their respective composts were extracted with water and hydrogen peroxide. Carbon and nitrogen determinations were conducted on all the samples.

TECHNIQUE AND METHODS

Twenty grams of oven-dry materials of known carbon-nitrogen ratios were fermented aerobically in bottles. Each bottle was given an inoculum from a compost so as to ensure a rapid and even growth of flora. Nitrogen in different forms

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was introduced at the rate of 1 gm. per 100 gm. of material and the moisture content was adjusted to about 70 per cent. Frequent stirring of the contents was resorted to in order to obtain uniform moisture distribution. This would avoid any chances of waterlogging. After the desired period each bottle was weighed with its contents and analysed as shown below:

1. Extraction with hydrogen peroxide—the method employed was described by Shrikhande [1933, 2]. The strength of peroxide used was 3 per cent.
2. Extraction with water—2 gm. of the vegetable material and its compost were extracted with the same volume of water and for the same length of time as with peroxide.
3. Ammonia and nitrate N were estimated by methods described by Shrikhande [1941].
4. Total N w s determined by the usual Kjeldahl method using sulphuric-salicylic acid mixture only where nitrate was present.
5. Organic C was determined by the Robinson, McLean and Rice Williams method [1929].

Results

Series I—Carbon-nitrogen ratios of various materials

Table I contains figures of carbon, nitrogen and C/N ratios of the plant materials. It will be noted from the data that the variation in carbons is less striking than in the nitrogen of the different plant materials. It appears as though the distribution of carbon is more even in this class of materials than nitrogen. Knowing therefore the approximate age of any such material it may be possible to roughly estimate its carbon content but not so with the nitrogen. On an average the value of carbon may be assessed at 40 per cent in a moderately aged material. The carbon-nitrogen ratios of all the materials except those of Maana grass, Grevillea, cane-reed and paddy straw approximate to a figure which is obtained by composting an average vegetable material. This seems to be the fundamental reason why such materials have been generally used as green manures on tea estates without precomposting them before incorporating them into the soil. Adhering therefore to the basic conceptions of composting, the principle of using such materials as green manure appeared to be quite sound The fact that this conception has recently been called in question made further investigation of the decomposition of green manures desirable.

Table I

Carbon-nitrogen ratios of the unfermented materials

Material	Carbon	Nitrogen	C/N
Sun flower ..	36·91	3·37	10·96
Tephrosia ..	43·40	3·46	12·56
Refuse tea ..	42·73	3·97	10·75
Dadaps ..	40·62	2·54	15·97
Gliricidia ..	40·48	2·74	14·77
Maana grass ..	39·92	1·08	37·0
Tea leaf (prunings) ..	42·63	3·19	13·38
Weeds ..	34·99	2·01	17·43
Fern ..	41·01	1·79	22·88
Cane reed ..	36·92	0·96	38·50
Grevilleas ..	48·78	1·04	47·10
Paddy straw ..	34·59	0·78	44·12

Series II—Carbon-nitrogen ratios of residues obtained on water and peroxide treatment of plant materials

The object of such extractions was to see whether there existed any difference between the two extracting reagents and if so how one extraction differed from the other. Another reason for this series was to find out how much of the nitrogen in the plant material is easily available on the supposition that easily soluble nitrogen is readily available to the plant and micro-organisms because of its quick ammonification and subsequent nitrification Such an assumption appears reasonable since plants must obtain their nitrogen in soluble form. The work of Heck and Whitting [1927], Heck [1929] and of Bedsole [1937] lends support to such a hypothesis. Bedsole [1937] analysed a number of weeds common to Florida for their water soluble and total nitrogen contents and also studied their nitrification in the soil. He found that water soluble nitrogen was the most important factor in promoting nitrification followed by total N. If the water soluble N

was 0·5 per cent or above, favourable nitrate accumulation occurred, even though the total N was less than 1·7 per cent. Plants above 1·7 per cent total N but less than 0·33 per cent water soluble N had a slow accumulation of nitrate in the soil.

Water extraction. In materials of a low carbon-nitrogen ratio, it will be seen from Table II that Tephrosia and Dadaps gave the lowest extracts. The foliage leaf gave a lower extract than refuse tea, which is a product of manufacture from younger leaf. All materials with a wide carbon-nitrogen ratio gave extracts lower than materials rich in protein.

TABLE II

Extraction of unfermented material with H_2O & H_2O_2 (Residues)

Material	H_2	H_2O_2
Sun flower	77·5	65·5
Tephrosia	81·0	79·2
Refuse tea	70·2	72·0
Dadaps	81·2	71·8
Gliricidia	71 8	58·8
Maana grass	82·2	75·4
Tea leaf	78·2	45·9
Grevilleas	91·8	58·7
Weeds	74·2	73·6
Fern	74·8	59·0
Cane reed	83·1	76·5

Carbon-nitrogen ratios of residues are included in Table III. When the data in Tables I and III are compared an estimate can be made of the losses suffered by carbon and nitrogen during water extraction. The loss of carbon varies between 3 and 11 per cent for all the materials. Taking into account the criteria established by Bedsole [1937] for easy nitrification of plant materials it will be observed that all the materials of a low carbon-nitrogen ratio except Gliricidia fall into this category. All of them have a total N content over 1·7 per cent with a water-soluble N content very much in excess of 0·33 per cent and hence should be easily nitrifiable. Materials with a naturally wide carbon-nitrogen ratio do not conform to such a condition and hence are not liable to quick nitrification. This observation taken in conjunction with the principles of composting is strong evidence in support of the practice of green manuring with materials of a low carbon-nitrogen ratio. Carbon-nitrogen ratios of residues are practically of the same order as those of fresh materials, suggesting thereby that both carbon and nitrogen have been removed in a similar definite proportion.

Hydrogen peroxide extraction. Referring back to column 2 in Table II it will be noticed that the residues obtained are lower than those after water extraction, with the exception of refuse tea. This anomalous behaviour of refuse tea can be accounted for by the fact that considerable changes occur during tea manufacture from fresh tea leaf and that the tannin present very readily forms insoluble oxidation products even from a water extract, much more so in a peroxide extract.

Looking once more to Table III we can see that the loss of carbon with peroxide falls between 6 and 19 per cent. Maana as with water gives the lowest loss and tea leaf suffers the

TABLE III

C : N ratios of residues on extraction of original materials with H_2O and H_2O_2

Material	C/N of the H_2O extracted material (Residues)			C/N of the H_2O_2 extracted material (Residues)		
	C.	N.	C/N	C	N	C/N
Sun flower	31·46	2·80	11·26	25·81	1·54	16·76
Tephrosia	34·98	2·50	14·03	35·30	2·35	15·02
Refuse tea	31·34	2·87	10·91	32·63	2·86	11·39
Dadaps	35·19	1·67	21 03	30·56	1·19	25·76
Gliricidia	33·06	2·51	13·15	25·33	2·39	10·62
Maana grass	36·42	1·06	34·41	33·40	0·73	45·50
Tea leaf	36·29	2·39	15·21	23·02	1·12	20·59
Grevilleas	28·10	1·66	16·92	28·84	1·73	16·67
Weeds	31·59	1·59	19·85	24·85	1·29	19·31
Fern	32·86	0·84	39·23	30·26	0·60	50·44
Cane reed	42·01	1·03	40·86	21·21	0·36	63·24

highest. The extraction of nitrogen with peroxide is much more than in the case of water. Peroxide thus appears to attack the nitrogenous complex more than other constituents except in Gliricidia and weeds. The exceptional behaviour of proteins in Gliricidia continues to be the same as with water although greater carbon has been knocked off by peroxide. In the case of weeds, extraction with water and peroxide produced identical results in respect of both carbon and nitrogen. This is suggestive of the difference between the proteins of Gliricidia and weeds from proteins of other tissues. Due to the higher extraction of protein with peroxide the carbon-nitrogen ratios of residues are higher than the parent materials, with the exception of weeds.

If the analogy of quick nitrification in relation to water-soluble N and total N is stretched a little further it may be suggested that the peroxide soluble N may form the upper limit for this nitrogen to become available by mineralization since it has been shown by Iyer *et al.* [1934] that oxidizing agents present in the soil assist in the liberation of plant food.

From the data presented in Tables II and III the difference between the strengths of water and peroxide as extracting reagents has been well established. Hydrogen peroxide has removed more of both carbon and nitrogen than water.

Series III—Nitrogen transformations with respect to losses of dry matter during decomposition

Results of analysis are given in Table IV. Fungus mycelium appeared on the 3rd or the 4th day and active growth was noticeable after a week with the exception of maana and fern with no supply of artificial nitrogen. This is obviously due to the low nitrogen content of the two materials. Every bottle when stirred smelt profusely of amonia after a fortnight's decomposition barring materials of a wide carbon-nitrogen ratio and of tea leaf without any treatment although it has a narrow carbon-nitrogen ratio. This observation was confirmed by the actual amounts of ammonia recovered on distillation. But the absence of even a trace of ammonia from tea leaf is highly striking when compared to the behaviour of other protein-rich materials. Refuse tea which is a product of manufacture of tea flush produced some ammonification but this may be due to some modifications caused during manufacture. These observations have been confirmed by repetition. Sun-flower although so rich in protein also gave a low recovery of ammonia but this can be reconciled with the fact that it has only a small negative nitrogen factor while fermenting alone and actually ends with a positive nitrogen factor [Richards and Norman, 1931] in presence of sulphate of ammonia. Tea leaf although it gave such a high negative nitrogen factor showed no signs of ammonification suggesting thereby that the loss of nitrogen is in the form of elementary nitrogen [Eden and Shrikhande, 1939]. This anomalous behaviour may be attributed to the presence of tannin in tea leaf. This aspect of the problem is examined in a greater detail in a separate communication. The very small positive nitrogen factor for maana may either be due to the absorbtion of ammonia from other bottles or it may be an experimental error. The losses of dry matter are normal and they seem to depend upon the nitrogen content of green manures.

Although there is no need of any external supply of soluble nitrogen for fermenting materials of a low carbon-nitrogen ratio, fermentations were conducted under such conditions by way of academic interest. It will be noted that sun-flower, though it possesses more than enough protein for its decomposition has actually finished with a positive nitrogen factor in the presence of sulphate of ammonia. This observation finds support in the findings of Richards and Norman [1931], who also obtained a similar positive nitrogen factor with willow peelings with a high protein content. They have attributed this to the preferential utilization of ammonia over the plant protein. All the materials including tea leaf have produced ammonification. Such ammonification in tea leaf suggests that tea tannin has no effect on the ammonification of a material which is introduced externally but it does seem to interfere with the ammonification of its own protein suggesting some sort of association or linkage between the protein in the material. A fairly high recovery of ammonia on distillation in the case of Grevillea can be explained by taking into account the extremely refactory nature of the material as seen by the poor loss of dry matter of 7 per cent The complete recovery of total nitrogen with negligible losses of dry matter clearly denote that the microbiological activity was insignificant and hence there was no material change both in the mineral and total nitrogen All other materials of a wide carbon-nitrogen ratio finish with a positive nitrogen factor as anticipated. When the losses of dry matter with ammonium sulphate are compared with those with no treatment it will be noticed that they are lowered by an extra dose of nitrogen. This is in accord with the findings of previous workers.

There are two points which are worthy of

TABLE IV

Loss of dry matter and nitrogen transformation occurring during decomposition for 35 days
(Results expressed on 100 gm. original material)

Material	Initial T.N.	Initial M.N.	Dry matter	Final T.N	NH_3-N	NO_3-N	Organic N	Nitrogen factor
No Treatment								
Sun flower	3·37		58·4	3·38	0·14		3·25	— 0·12
Tephrosia	3·46		59·0	3·52	0·56		2·95	— 0·50
Refuse tea	3·97		56·5	3·68	0·20		3·48	— 0·50
Dadaps	2·54		48·7	2·00	0·36		1·64	— 0·90
Gliricidia	2·74		51·3	2·56	0·78		1·78	— 0·96
Maana grass	1·08		67·6	1·09	..		1·09	+ 0·01
Tea leaf	3·19		62·4	2·40	..		2·40	— 0·79
Weeds	2·01		49·0	1·81	..		1·81	— 0·20
Grevilleas	1·04		..	..	..		..	..
Fern	1·79		78·1	1·57	..		1·57	— 0·22
Cane reed	0·96		..	..	..		..	..
Paddy straw	0·78		..	..	..		..	..
Ammonium sulphate								
Sun flower	4·54	1·17	79·1	4·61	0·94		3·67	+ 0·30
Tephrosia	4·57	1·11	69·0	4·28	1·56		2·72	— 0·73
Refuse tea	5·01	1·04	76·7	4·47	1·34		3·13	— 0·85
Dadaps	3·65	1·11	80·0	3·34	1·01		2·33	— 0·21
Gliricidia	3·83	1·09	59·4	3·47	1·29		2·17	— 0·57
Maana grass	2·18	1·10	66·3	0·19	0·91		1·28	+ 0·20
Tea leaf	4·24	1·05	68·4	3·54	0·78		2·68	— 0·51
Weeds	3·09	1·08	45·9	2·39	0·51		1·88	= 0·13
Grevilleas	2·14	1·10	92·9	2·12	0·79		1·33	+ 0·29
Fern	2·87	1·08	75·6	2·61	0·92		1·17	— 0·10
Cane reed	2·06	1·10	65·3	1·66	0·48		1·17	+ 0·21
Paddy straw	1·87	1·09	75·1	1·68	0·08		1·00	+ 0·22
Sodium nitrate								
Sun flower	4·49	1·12	66·8	3·19	0·42	..	2·77	— 0·60
Tephrosia	4·57	1·11	71·6	3·04	0·51	0·26	2·27	— 0·19
Refuse tea	5·01	1·04	74·6	4·58	0·61	0·72	3·25	— 0·72
Dadaps	3·65	1·11	73·3	3·04	0·33	1·27	1·44	— 0·11
Gliricidia	3·83	1·09	61·3	3·07	0·39	0·55	2·13	— 0·61
Maana grass	2·78	1·10	59·7	1·69	..	0·47	1·22	+ 0·14
Tea leaf	4·24	1·05	70·0	3·46	..	0·48	2·98	— 0·21
Weeds	3·09	1·08	57·0	2·14	0·16	0·04	1·94	— 0·07
Grevilleas	2·14	1·10	94·7	1·94	..	0·86	1·08	+ 0·04
Fern	2·87	1·08	67·5	2·22	..	0·43	1·79	..
Cane reed	2·06	1·10	62·6	1·57	..	0·62	0·95	— 0·01
Paddy straw	1·87	1·09	84·6	1·80	..	0·60	1·19	+ 0·41

note in the sodium nitrate series. Firstly, the recovery of mineral nitrogen is not so high as with ammonium sulphate. Secondly the nitrogen factors have a greater negative value. This can be attributed to the losses of nitrogen due to denitrification. Here again, the losses of dry matter are affected by an excessive doze of nitrogen as in the case of ammonium sulphate. The extremely poor decomposition of Grevillea both with ammonium sulphate and sodium nitrate indicate the extremely resistant nature of this plant tissue. It should be incorporated into the soil with a proportionate dose of nitrogen, or else it should form a good resistant material to be composted with green manures.

Series IV—Carbon-nitrogen ratios of composts

These ratios are contained in Table V. The recovery of carbon with all the three types of composting is practically of the same order. It is however lowered in general by 10 to 15 per cent when compared with the carbon content

of fresh materials. Nitrogen in composts without any treatment follows a similar course as the parent materials with an exception in tea leaf. The carbon-nitrogen ratios of all the composts are lower than those of original materials.

TABLE V

Carbon-nitrogen ratios of fermented materials (35 days)

Material	Carbon	Nitrogen	C/N
No treatment			
Sun flower	21·97	3·38	6·49
Tephrosia	25·87	3·52	7·35
Refuse tea	29·12	3·68	7·91
Dadaps	20·94	2·00	10·46
Gliricidia	21·64	2·56	8·47
Maana grass	28·72	1·09	26·32
Tea leaf (prunings)	29·22	2·40	12·20
Weeds	14·16	1·81	7·81
Fern	30·99	1·57	19·72
Cane reed	..	..	..
Paddy straw	..	..	..
Ammonium sulphate			
Sun flower	26·07	4·61	5·65
Tephrosia	27·01	4·28	6·30
Refuse tea	24·01	4·47	5·37
Dadaps	30·79	3·34	9·22
Gliricidia	23·34	3·47	6·74
Maana grass	27·75	2·19	12·68
Tea leaf (prunings)	29·60	3·45	8·57
Weeds	14·22	2·39	5·96
Fern	28·56	2·61	10·92
Cane reed	24·10	1·66	14·55
Paddy straw	18·30	1·68	10·87
Sodium nitrate			
Sun flower	23·42	3·19	7·33
Tephrosia	28·27	3·04	9·30
Refuse tea	28·43	4·58	6·21
Dadaps	24·40	3·04	8·03
Gliricidia	23·14	3·07	7·54
Maana grass	26·84	1·69	15·88
Tea leaf (prunings)	28·21	3·46	8·15
Weeds	15 13	2·14	7·06
Fern	22·85	2·22	10 29
Cane reed	18·77	1·57	11·98
Paddy straw	..	..	..

The carbon recovery of composts obtained with sulphate of ammonia and sodium nitrate is in general the same as with no treatment, but the nitrogens are apparently higher than compost without any treatment on account of the mineral nitrogen added. The carbon-nitrogen ratios are thus narrower than those of original materials. Comparing sulphate of ammonia with sodium nitrate rots it can be seen that the carbons for both are similar but not so with nitrogen. Nitrogen in sodium nitrate rots are lower due to losses on denitrification and hence the carbon-nitrogen ratios are wider here than in ammonium sulphate rots.

In actual practice, an attempt should never be made to compost such materials in presence of additional mineral nitrogen. The carbon-nitrogen ratios of composts obtained without any treatment are in themselves highly significant. Their ratios have become narrower than 10 : 1. The average ratio obtained on composting a fairly resistant material is usually of the order of 12 : 1. Attempting to ferment materials of narrow C/N ratios is to involve oneself in an undesirable waste both of carbon and nitrogen which are so essential for the growth of plants and organisms. In fact to compost such a material is to defeat the very object of composting. The principle of composting really consists in fermenting materials of wide carbon-nitrogen ratios in the presence of a suitable source of available nitrogen, so as to bring down the ratio to that of soil humus (near 10 : 1) which is the optimum for easy nitrification.

There are, therefore, only two ways in which such materials can be successfully used, (1) by composting them with some resistant materials, (2) using them as green manures by digging them into the soil. Ammonia which is liable to be lost under ordinary composting will be profitably utilized either by the micro-organisms in elaborating microbial tissue under the first head or the ammonia as such may be absorbed by the soil complex thus preventing the whole of it being lost on volatilization as the growing crop may use it in the form of nitrate. The first principle was successfully adopted by Brown and Smith [1929] in composting straw in presence of clover and unsuccessfully by Bagot [1936] by composting green manure alone.

Series V—Carbon-nitrogen ratios of residues obtained after extraction with water and peroxide of composts

These determinations were conducted only on composts obtained without any treatment.

Water extraction. When these residues after water extraction in Table VI are compared with those obtained from original materials, it will be noted that the residues from composts are lower than those obtained from the parent material. Such a difference can be accounted for by the fact that certain constituents in the original material have been partly rendered soluble and partly destroyed by the micro-organisms during the process of decomposition.

TABLE VI

Extraction of fermented material with H_2O & H_2O_2 (Residues)

Material	H_2O	H_2O_2
Sun flower ..	..	..
Tephrosia ..	51·51	26·2
Refuse tea ..	56 0	44·3
Dadaps ..	60·7	34·0
Gliricidia ..	42·8	39·7
Maana grass ..	42·9	34·2
Tea leaf (prunings) ..	54·8	43·0
Weeds ..	56 0	31·9
Fern ..	32·6	19·1

By studying Table VII along with Tables V and III it will be seen that both the factors are at play in giving lower residues from composts. Carbons in Tables V and VII are in general of the same magnitude showing that very little carbon is water soluble whereas in certain cases over 30 per cent of nitrogen has been rendered water soluble in composts. That is why the carbon-nitrogen ratios of residues have gone up in their values. If both the carbons and nitrogens in Table VII are compared with those in Table III it will be found that they are lowered by about 30 and 20 per cent respectively. Both these constituents are apparently lost during decomposition, viewing the water solubility of nitrogen in a compost as a test of quick nitrification and easy availability, as discussed previously, we can conclude that 30 per cent of nitrogen in such composts should become easily available to the crop.

Peroxide extraction. Comparing again peroxide residues of composts in Table VI with those in Table II of fresh materials it can be observed that there is a considerable difference

TABLE VII

C/N ratios of residues on extraction of fermented materials with H_2O and H_2O_2

Material	(H_2O)			(H_2O_2)		
	C%	N%	C/N	C/N	N%	C%
Sun flower	20·74	2·29	9·04	9·73	0·74	13·18
Tephrosia	25·04	1·90	13·20	18·61	1·56	11·91
Refuse tea	26·50	2·87	9·22	14·88	2·30	6·48
Dadaps	20·15	1·10	18·28	17·23	0·83	20·71
Gliricidia	18·72	0·97	19·22	14·83	0·50	29·76
Maana grass	24·63	1·20	20·56	19·07	0·63	30·43
Tea leaf (prunings)	28·03	2·03	13 84	13·39	1·25	10·71
Weeds	11·94	1·20	9·91	6·30	0·30	21·44
Fern	30·71	1·57	19·54	21·69	0·99	21·80

between the two. That peroxide extracts much more than water can be cleary seen by comparing their respective residues in Table VI.

Arguing on similar lines as in Series II, we can say that peroxide extracted more of carbon and nitrogen from composts than water. About 25 to 30 per cent of carbon has been removed and nitrogen extracted in several cases has exceeded 60 per cent. Comparing the data in Tables III and VII it can be seen that approximately 40 per cent of carbon and nearly an equal amonnt of nitrogen have been apparently lost during decomposition of most materials of a narrow carbon-nitrogen ratio. 60 per cent which is shown to be peroxide soluble N may be taken as the upper limit for available N in composts since oxidizing agents present in the soil assist in the liberation of plant food [Iyer *et al.* 1934].

The figure quoted by various workers on the availability of nitrogen in composts and farmyard manure ranges between 33 and 68 per cent. These values were arrived at either by following the ammonification and nitrification and changes in soil with a manure or by the amount of nitrogen recovered in the growing crop. Tuxen [1884] for instance recovered only 33 per cent of N in farmyard manure as nitrate in five months. Iversen [1927] recovered 26-68 per cent over a period of eight years in his wheat crop and Popp [1908] noted that six weeks were required to nitrify 33 per cent N in manure.

All the above data also clearly demonstrate the greater action of peroxide than water over both composts and fresh vegetable tissues. These findings thus contradict the observations of Richardson [1931], who noted practically no

difference between the two extracting reagents.

Series VI—Comparison of the rate of nitrification of different materials

All the materials were ground to pass 64-mesh sieve. Nitrification tests were conducted at room tempetrature of about 25°C. The amount of N in each container was adjusted to 40 p.p.m. and each treatment was quadruplicated. 100 gm. of sand was taken in each container and the moisture content was maintained at 10 per cent. After seven weeks all the cultures were tested for mineral N by the Mclean and Robinson method [1924]. The results are summarized in Table VIII. It is interesting to note that the lowest limit of N for nitrification from this data is set at 1·79 per cent which is in accord with the well establishd concept. Lyon, Bizzell and Wilson [1923] showed that nitrate is taken up from the soil during the decomposition of plant residues containing less than about 1·8 per cent N: this amount, however, seemed to keep the process self-supporting. Materials containing more N than this increased the NO_3 content of the soil. This observation is also in keeping with the results in Table IV on the decomposition of materials in bottles when materials below 1·79 per cent have not undergone any change without an external supply of available N. The percentages of total nitrification appears to be proportional to the initial total N content of the materials with an exception in refuse tea which contains about 18 per cent tannin, but there seems to be no strict relation hip between nitrification and water-soluble N as suggested by Bedsole [1937].

TABLE VIII

Mineralization of nitrogen in original materials

Material	NO_3 p.p.m.	Nitrification per cent of total nitrogen	Percentage of total N in the material	Percentage of H_2O soluble nitrogen	Percentage of H_2O_2 soluble nitrogen
Sun flower	8·29	20·68	3·37	0·57	1·83
Gliricidia	9·29	23·24	2·74	0 23	0·35
Tephrosia	17·20	43·00	3·46	0·96	1·11
Dadaps	2·80	6·99	2·54	0·87	1·35
Refuse tea	2·24	5·60	3·97	1·10	1·20
Weeds	6·03	15·09	2·01	0·35	0·28
Fern	4·70	11·74	1·79	0·20	0·50
Maana grass	..	..	1·08	0·02	0·35
Grevilleas	..	..	1·04	0·01	0·67
Cane reed	..	..	0·96	0·15	0·36
Paddy straw	..	..	0·78	..	..

SUMMARY AND CONCLUSIONS

Decomposition of green manures and other suitable material for composting on tea estates in Ceylon has been studied with respect to their carbon-nitrogen changes, with the following observations:

(1) The composition of various materials examined shows that the carbon-nitrogen ratio of all the green manures is in the neighbourhood of 12 : 1, a ratio obtained in a compost of an average vegetable material. Some uniformity in the distribution of carbon in these materials has been suggested

(2) Hydrogen peroxide produces a greater loss on extraction of fresh materials than water. Peroxide extracts more of carbon and nitrogen than water. The carbon-nitrogen ratios of residues on water extraction are of the same order as of the original materials, but not so with peroxide residues.

(3) All the green manures have finished with a negative nitrogen factor with ready ammonification of the plant protein, with the exception of tea leaf. The leaf with its normal decomposition and negative nitrogen factor, failed to produce any ammonia, suggesting that the loss is perhaps due to elementary nitrogen. The possibility of interference due to the presence of tannin in tea leaf has been sugge ted. Sun flower although rich in nitrogen has nevertheless immobilized some ammoniacal nitrogen and finished with a positive nitrogen factor.

(4) Carbon-nitrogen ratios of all the composts from green manures are narrower than those of parent materials. The futility of composting such green manures has been explained on the basis of nitrogen factors as tremendous losses of nitrogen occur during such a process. Two profitable ways of using such materials have been indicated.

(5) Hydrogen peroxide produces a greater loss on extraction of composts than water. Both carbon and nitrogen are lost in greater amounts with peroxide. The carbon-nitrogen ratios of peroxide residues are narrower than the composts. About 30 to 60 per cent of nitrogen which is attacked by peroxide in composts may be taken as the amount which may become available to the plant by mineralization.

(6) Comparative tests on nitrification indicate a relationship between total nitrates formed and initial total nitrogen content of plant residues but no strict relation is traceable between nitrification and water-soluble nitrogen as suggested by Bedsole [1937]. 1·79 per cent N in fern sets the low st limit to nitrification in the series tested. This limit agrees with the well established concept that about 1·8 per cent N in a material keeps the process of nitrification self-supporting.

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PROPERTIES OF SYNTHETIC MIXTURES

II. MIXTURES OF COLLOIDAL SOLUTIONS OF SILICIC ACID, ALUMINIUM HYDROXIDE AND FERRIC HYDROXIDE*

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(With two text-figures)

THE electrochemical properties of mixtures of colloidal solutions of silicic acid and aluminium hydroxide have been discussed in Part I of this paper [Chatterjee and Sen, 1943, 1]. The present paper** deals with the properties of synthetic mixtures of silicic acid, aluminium hydroxide and ferric hydroxide sols

The methods of preparation of colloidal silicic acid and aluminium hydroxide have been reported in the previous part. Ferric hydroxide sols were prepared by adding, drop by drop, a saturated solution of ferric chloride to boiling water The hydrochloric acid generated in the process and the unhydrolysed ferric chloride, if any, were removed by dialysis. Final purification was effected by electrodialysis.

Two mixtures were prepared by mixing the pure sols in different proportions. Mutual coagulation was noticed when the sols were mixed and the coagulated mass settled down after some time.

(a) *Chemical composition*

Percentages of silica, alumina and ferric

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oxide in the mixtures and their silica-sesquioxide ratios are shown in Table I.

TABLE I

Mass-chemical composition of over dried mixtures of silica, alumina and ferric oxide

System	SiO_2%	Al_2O_3%	Fe_2O_3%	SiO_2/P_2O_3 (molar)
Mixture I ..	60·11	23·72	15·81	3·10
Mixture II ..	51·22	36·02	11·96	1·95

(b) *Effect of ageing on pH and conductivity*

Variations in the *p*H and specific conductivity of mixtures I and II with time are shown in Tables II and III.

TABLE II

Variations in the pH of synthetic mixtures with time

System	Colloid content gm. per litre	*p*H				
		17-3-41	19-3-41	20-3-41	25-3-41	30-3-41
Mixture I	4·3	4·50	4·23	4·21	4·03	4·05
Mixture II	4·3	4·30	4·30	4·18	4·08	4·11

TABLE III

Variations in the specific conductivity of synthetic mixtures with time

System	Specific cond. $\times 10^5$ mho.			
	17-3-41	19-3-41	20-3-41	25-3-41
Mixture I ..	4·61	5·08	5·20	5·25
Mixture II ..	4·45	4·81	5·00	5·02

The data cited in Tables II and III show that ageing has a definite effect on the *p*H and conductivity as also observed with the binary mixtures of colloidal silica and aluminium hydroxide previously studied [Chatterjee and Sen, 1943, 2]. The variations of the *p*H and conductivity indicate a slow interation between the colloidal solutions. In the case of mixtures I and II the *p*H decreases and the specific conductivity increases with time (Tables II and III) but the mixtures previously studied showed an increase in both the *p*H and specific conductivity. Ray chaudhuri and Mian [1943] consider that ageing favours a mineralization of the mixed gels.

(c) *Interaction with alkalis*

The potentiometric titration curves (Fig. 1) of the mixtures with NaOH differ from that of any of the ingredients in that the former show a definite inflexion point between *p*H 7·0 and 7 6 which is lacking in the titration curves of the pure systems [Chatterjee, 1939; Datta, 1939; Mukherjee *et al.*, 1942]. Similar observations were made with the binary mixtures and also with some hydrogen clays previously studied in this laboratory [Chatterjee & Sen, 1943; Mukherjee *et al.*, 1942]. Puri, *et al.* [1944] have recently observed a similarity of the titration curves of soil colloids with those of synthetic mixtures of ferroaluminium silicates. The inflexion is sharper the higher the SiO_2/R_2O_3 ratio of the mixture (Fig. 1), The form of the titration curve and the inflexion point suggest that some sort of interaction takes place on mixing the three soils.

*p*H and total acids calculated from titration curves are shown in Table IV which also includes similar data* on a hydrogen clay L (isolated from a lateritic soil) having the same mass chemical composition as mixture II.

TABLE IV

pH and total acids of synthetic mixtures

System	*p*H	SiO_2/R_2O_3	Total acid, milli-equivalents per 100 gm.		*p*H at inflexion
			At inflexion point	At *p*H 7·0	
Mixture I ..	4·05	3·10	23·0	23·0	7·0
Mixture II ..	4·11	1·95	24·0	11·0	7·65
Hydrogen clay sol L	4·80	1·95	15·5	5·5	8·20

As usually found with hydrogen clays isolated from soils, the amount of the acid neutralized at *p*H 7·0 increases with the SiO_2/R_2O_3 ratio of the mixture. At the inflexion point, however, both the mixtures give almost the same total acidity.

Mixture No. II gives a greater total acid (calculated at the inflexion point, or at *p*H 7·0) than hydrogen clay L having a similar chemical composition. A higher *p*H at inflexion is found for the hydrogen clay, compared with this mixture.

(d) *Buffer capacities*

The potentiometric titration curves resemble that of a weak acid in true solution. It was,

* Taken from a paper by Dr R. P. Mitra [1942]

herefore, thought desirable to study their buffer-apacity curves with a view to having fuller nformation on this point. Buffer capacities $\triangle B/\triangle pH$) calculated from different points of

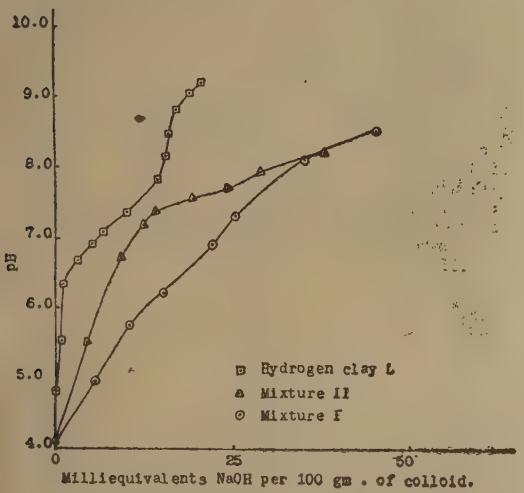

Fig. 1. Titration curves of the mixtures and hydrogen clay L with NaOH

he titration curves are plotted against the con-entration of the added alkali in Fig. 2. On the ddition of alkali, the buffer capacity gradually ncreases and after passing through a maximum nd a minimum, it again increases. The maxi-num point in the buffer capacity curves does not orrespond with the point of half neutralization

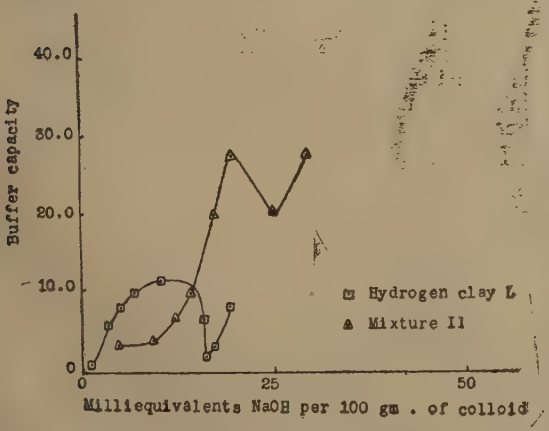

Fig. 2. Buffer capacity curves of mixture II and hydrogen clay L

but is shifted to a higher alkali concentration. The synthetic mixtures as also sol L differ from a dissolved weak acid in this respect. The similarity in the forms of the titration curves of these systems with that of a weak acid in true solution is, therefore, only superficial.

Mixture No. II shows a greater buffering than the hydrogen clay sol L (Fig. 2) though both have the same mass chemical composition. Similar observation was made by Bradfield [1923]. He found that a synthetic mixture of purified aluminium hydroxide, ferric hydroxide and silicic acid having the same composition as the colloidal material isolated from a heavy clay subsoil showed a stronger buffer capacity towards alkalis than the natural colloid.

(e) *Liberation of Al ions from the mixtures by neutral salts*

The supernatant liquids above mixtures I and II to which 0·09N $BaCl_2$ had been added were analysed for Al and Fe and the results are recorded in Table V. Similar data on hydrogen clay L are also given in that table.

TABLE V

Analysis of salt extracts of synthetic mixtures and hydrogen clay

System	SiO_2/R_2O_3	Milliequivalent of Al displaced per 100 gm.	Milliequivalent of Fe displaced per 100 gm.
Mixture II	1·95	3·2	Nil
Mixture I	3·10	4·2	Nil
Hydrogen clay sol L ..	1·95	12·0	Nil

Appreciable quantities of Al are liberated from all three systems though the hydrogen clay gives a much larger quantity of Al than either mixture. No Fe could be detected in the supernatant liquid.

SUMMARY

The *p*H and conductivity of two mixtures having different proportions of colloidal silica, alumina and ferric hydroxide change on ageing indicating a slow interaction between the ingredients.

Potentiometric titration curves of the mixtures with NaOH show a definite inflexion between *p*H 7·0 and 7·6 which is not found in the titration curves of any of the ingredients.

The total acidity at *p*H 7·0 calculated from the titration curve increases with $SiO_2/R\ O_3$ ratio

of the mixture but at the inflexion point both the mixtures give almost the same total acid. The *p*H at inflexion is lower the higher the SiO_2/R_2O_3 ratio.

One of the mixtures shows a greater buffering towards alkalis than a hydrogen clay having the same mass chemical composition.

Appreciable quantities of Al are liberated from the mixtures on the addition of $BaCl_2$ (0·09N). Fe could not be detected in the salt extract.

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STUDIES IN INDIAN CEREAL SMUTS
VII. FURTHER STUDIES IN VARIETAL RESISTANCE OF INDIAN AND OTHER WHEATS TO LOOSE SMUT

By B. P. Pal and B. B. Mundkur, Imperial Agricultural Research Institute, New Delhi

(Received for publication on 12 December 1944)

In a previous communication the authors [Mundkur and Pal, 1941] gave the results of testing nearly 100 varieties of wheat against a race of loose smut originally collected at Pusa. Subsequent studies indicated that there are probably two races of loose smut in this country The tests with the original race, which will for convenience be referred to as L_1, were therefore continued, while at the same time the varieties were also tested for their reaction to the second race which will be referred as L_2. The latter was originally collected at Delhi in 1939. The complete results for the period of the investigations (1937-1944) are set forth in Table I. With the increase in the amount of material handledl it was not possible to test all the varieties in ale the years. Taken collectively, however, th- results constitute a statement of relative resistance of important Indian and foreign varieties which should be of interest and value to wheat breeders in India, and possibly also to those working in other countries.

The methods of infecting the ears, etc. are identical to those employed before and described in the communication referred to above, and hence they are not again described here.

The first article of this series appeared in the *Proc. Indian Acad. Sci.* **9**: 267-70 (1939), and the remaining ones in the *Indian J. agric. Sci.* **11**: 675-86, 687-94; 695-702; **13**: 54-58, 631-33

TABLE I

Reaction of wheat varieties to two races of loose smut

Variety	Reaction to race L_1 — Percentage of smutted plants in							Rection to race L_2 — Percentage of smutted plants in				
	1937-38	1938-39	1939-40	1940-41	1941-42	1942-43	1943-44	1939-40	1940-41	1941-42	1942-43	1943-44
Indian varieties												
Imperial Pusa 4	23·0	92·4	67·0	34·8				28·0	36·6	0·0		29.1
„ „ 12	58·4	94·4									38·7	50·4
„ „ 52	30·8	91·8	62·7	12·6					78·3	3·1	64·1	17·4

TABLE I (*contd.*)

Variety	Reaction to race L_1 — Percentage of smutted plants in							Reaction to race L_2 — Percentage of smutted plants in				
	1937-38	1938-39	1939-40	1940-41	1941-42	1942-43	1943-44	1939-40	1940-41	1941-42	1942-43	1943-44
Imperial Pusa 80-5	30·5	23·0	74·1	21·5					21·6	25·4	26·6	16·0
" " 101	80·8	91·0	90·6					88·3	86·6	41·9	63·8	34·8
" " 111	29·2	100·0	38·1	40·5					63·3	0·0	47·1	25·9
" " 114	0·0	0·0	0·0	0·0				0·5	6·8	0·0		
" " 120	9·7	0·0	0·0	0·0					0·8	0·4	0·0	0·0
" " 121	0·4	0·0	4·5	0·0				1·1	4·3	0·0	0·0	2·3
" " 122	20·6	0·0	0·3	0·0					2·7	0·0		
" " 123	11·4	91·4										
" " 124	0·0	0·0	0·0	0·0				9·3	2·0	0·0		
" " 125	14·2	64·5	14·9	34·3					50·0	0·6	51·4	23·5
" " 126	19·7	84·9										
" " 163-3		0·0	0·0	0·0							0·0	3·8
" " 163-4		0·0	0·0	0·0	0·0				1·8	0·0	55·8	3·1
" " 165		0·0	17·4	0·6	0·0			5·3	2·6	0·0		
" " 114-1-8			0·0	0·0							0·0	0·0
" " 120-7				0·0				0·0	0·0			
" " 120-8				0·0				0·0	0·0			
" " 120-19				0·0				0·0	0·0			
Punjab 8 A	13·9	93·1	49·1	55·1	75·8	45·2	26·4		70·1	53·5		53·5
" 9 D	45·5	100·0										
" C 518	52·5	96·4	66·3	34·1		57·2	68·4		83·4	7·5		50·9
" C 591	75·3	100·0	76·7	56·0	81·5	46·9	50·7					
Cawnpore 13	15·1	84·3	33.7	59·3					52·7	3·3		5.03
Foreign varieties												
Federation (New stock)	0·0	45·0						61·5	63·7	0·0		
" (Old, red-glumed)	0·0	0·0	0·0	0·0				0·0	0·0	0·0		
" (Old, white-glumed)	0·0	0·0	0·0	0·0	0·0			12·9	2·9	0·0		2·9
" (from Tarnab)	0·0	0·0	0·0	0·0	0·0			4·6	6·2		0·0	0·0
Chinese White		0·0	1·1	0·0	0·0	0·0	0·0		0·0			
Flora		0·0	0·4	0·0	0·0				0·0			
Sword		0·0	0·0	0·0	0·0				0·0			
Khapli (*T. dieoccum*)		0·0	0·0	0·0					0·0			
Free Gallipolli		0·0	0·0	0·0	0.0				0.0			
Igachikugo		0·0	0·0	0·0					0·0			
Eshimashiuraki		0·0	0·0	0·0	0.0							
Ford		0·0	0·3	0·0	0·0				1·6	0·0		
Dundee		0·0	0·0	0·0	0·0				0·0			
Florence		0·0	0·0	0·0	0·0				0·0			
C 5271-W1			18·7	15.1	22·1	0·0	0·0					
Kubanka (*T. durum*)				0.0	0·0							
Reliance				0·0			0·0				0·0	0·0
Mediterranean				0·0								
Hope				0·0			0·0				0·0	0·0
Kenya (E 144)				5·5	1·4	5·0	8·6				14.9	28·9
" (E 148)				1·6	24·0	2·9	60·2					
" (E 220)				0·0			0·0				0 9	0·6
Thatcher				0·0								
Ardito				6·6	14·6	0 0	12·7				2·0	6·4
Mentana				17·8	13·2	26·1	2·8				9·0	9·1

The results show that, generally speaking, various which are susceptible to race L_1 of loose smut are also susceptible to race L_2, although the degree of susceptibility may differ. Several varieties which are immune from or highly resident to L_1 are slightly susceptible to L_2; with the doubtful exception of Chinese White there seems to be no case, however, where a variety immune from or highly resistant to L_2 is susceptible to race L_1. While L_1 may be restricted to Eastern India and L_2 to Northern India, it is obvious that the wheat breeder must take both the races into account when breeding wheats for loose smut resistance and it is

fortunate that a number of wheats are immune from or highly resistant to, both the strains of loose smut. These include the commercially important Imperial Pusa 114, 120, 165 and Khapli, the following new or little-tried strains bred at the Imperial Agricultural Research Institure: IP 121, IP 122, IP 124, IP 163-3, IP 163-4, IP 114-1-8, IP 120-7, IP 120-8, and IP 120-19; also a large number of imported varieties including Federation (three strains out of four in our collection), the rust resistant Kenya wheats (E 114, E 148 and E 220) and Reliance.

Besides the varieties enumerated in Table I, 62 new strains of hybrid origin, bred in the Botanical Section of this Institute, have been tested. Of these, 22 proved immune from or very highly resistant to both the smut races, 12 proved very highly resistant to L_1 alone (six of these how ver were not tested at all against L_2), one proved very highly resistant to L_2 (this was not tested against L_1), while the remainder showed varying degrees of susceptibility ranging from about 5 per cent to 75 per cent.

Thus there are a large number of loose-smut resistant strains already available in India and these constitute ample basis for building up new wheats combining loose-smut resistance with other desirable characters.

Summary

1. The reaction of 26 Indian varieties and 25 foreign varieties of wheat to two races of loose-smut commonly occuring in India is given in detail. The results of tests with 62 new strains of hybrid origin are also briefy summarized.

2. Nearly 50 per cent of the varieties tested, including some strains which are not distributed to farmers, proved to be resistant to both the strains of loose smut. The remainder showed varying degrees of susceptibility to one or both the smut strains.

3. It is pointed out that there is ample material for breeding new wheat varieties combining resistance to loose-smut with other desirable characters.

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STUDIES IN INDIAN CEREAL SMUTS

VIII. NOMENCLATURE OF INDIAN SMUT FUNGI AND PROBABLE MODES OF THEIR TRANSMISSION

By B. B. Mundkur, Imperial Agricultural Research Institute, New Delhi

(Received for publication on 21 December 1944)

In a recent publication Stevenson and Johnson [1944] have reviewed the position regarding the names that should be applied to cereal smut fungi in order to strictly adhere to the International Rules of Botanical Nomenclature.

A majority of the Mycologists will be in complete accord with the conclusions of Stevenson and Johnson [1944]. Their list of names deals with only those smuts that occur in the U.S.A. A list which includes the smuts affecting the Indian crop plants has therefore been compiled and presented below.

The list also includes the available information regarding the modes of transmission of the smut diseases, wherever they are known. In the study of plant diseases, a knowledge of their mode of transmission is very important, for without such knowledge, it is not possible to devise proper control measures. Smuts may be externally seed-borne or internally seed-borne, soil-borne or air-borne. Methods developed for controlling externally seed-borne smuts are worthless for controlling internally seed-borne smuts. For smuts that are air-borne seed treatments are of no value.

Unfortunately we do not yet know the mode of transmission of all the smuts affecting our crop plants. Recently the author [1943] has shown that the Karnal bunt is air-borne. Probably the bunt of rice is also air-borne. It is hoped that the Mycologists in whose areas such smuts occur will be stimulated to do further research so as to fill the lacunae in our knowledge of the transmission of such smuts.

Previous contributions in this series appeared in *Proc. Indian Acad. Sci.* **11**, 267-70 (1939); *Indian J. agric. Sci.* **11**, 675-702 (1941); **13**, 54-58, 631-633 (1943)

Crop	Common name of smut	Scientific name according to		Mode of transmission
		International Rules of Botanical Nomenclature	Previous practice	
Wheat (*Triticum* spp.)	Loose smut	*Ustilago tritici* (Pers.) Rostr.	*Ust. tritici* (Pers.) Jens.	Internally seed-borne, (floral infection)
	Flag smut	*Urocystis tritici* Koern.	No change	Externally seed-borne
	Karnal bunt	*Neovossia indica* (Mitra) Mundkur	*Til. indica* Mitra	Air-borne, floral infection
	Rough spored bunt	*Tilletia caries* (DC.) Tul.	*Til. Tritici* (Bjerk.) Wint.	Externally seed-borne
	Smooth spored bunt	*Tilletia foetida* (Wallr.) Liro	*Til. foetans* (*B. and* C.) Trel. or *Til. levis* Kuehn	Externally seed-borne
Rice (*Oryza sativa*)	Leaf smut	*Entyloma oryzae* Syd.	No change	Not known
	Bunt	*Neovossia horrida* (Tak.) Padw. and Azmt.	*Til. horrida* Tak.	Probably air-borne (floral infection)
Jowar (*Sorghum vulgare*)	Grain or covered smut	*Sphacelotheca sorghi* (Link) Clint.	No change	Externally seed-borne
	Loose smut	*Sphacelotheca cruenta* (Kuehn) Potter	No change	Externally seed-borne
	Long smut	*Tolyposporium ehrenbergii* (Kuehn) Pat.	*Toly. filiferum* Busse	Probably air-borne (floral infection)
	Head smut	*Sphacelotheca reiliana* (Kuehn) Clint.	*Sorosporium reilianum.*	Probably soil-borne
Oats (*Avena* spp.)	Loose smut	*Ustilago avenae* (Pers.) Rostr.	*Ust. avenae* (Pers.) Jens	Externally seed-borne
	Covered smut	*Ustilago Kolleri* Wille	*Ust. levis* (Keller, and Sw.) Magn.	Externally seed-borne
Barley (*Hordeum* spp.)	Loose smut	*Ustilago nuda* (Jens.) Rostr.	*Ust. nuda* (Jens.) Kell. and Sw.	Internally seed-borne (floral infection)
	Covered smut	*Ustilago hordei* (Pers.) Lagerh.	*Ust. hordei* (Pers.) Kell. and sw.	Externally seed-borne
Maize (*Zea mays*)	Smut	*Ustilago mays-zeae* (DC.) Corda	*Ust. zeae* (Beckm.) Unger.	Air-borne
	Head smut	*Sphacelotheca reiliana* (Kuehn) Clint.	*Sorosporium reilianum* (Kuehn) McAlp.	Not known

Crop	Common name of smut	Scientific name according to		Mode of transmission
		International Rules of Botanical Nomenclature	Previous practice	
Bajra (*Pennisetum typhoides*)	Smut	*Tolyposporium penicillariae* Bref.	No change	Air-borne
	African smut	*Tolyposporium senegalense* Speg.	No change	Unknown
	Bunt	*Tilletia ajrekari* Mundkur	No change	Probably air-borne
Kagni or rale (*Setaria italica*)	Grain smut	*Ustilago crameri* Koern.	No change	Externally seed-borne
Chena (*Panicum miliaceum*)	Head smut	*Sphacelotheca destruens* (Sche.) Stev. and John.	*Ustilago panicimiliacei* (Pers.) Wint.	Externally seed-borne
Sawan (*Echinochloa frumentacea*)	Rough spored grain smut	*Ustilago panicifrumentacei* Bref.	No change	Not known
	Smooth spored grain smut	*Ustilago paradoxa* Syd. and Butler	No change	Externally seed-borne
	Inflorescence smut	*Ustilago crus-galli* Tracy and Earle.	..	Not known
Ragi or Nachni (*Eleusine coracana*)	Grain smut	*Melanopsichium eleusinis* (Kulk.) Mundkur and Thirumalachar	*Ust. eleusinis* Kulkarni	Probably air-borne
Kodra (*Paspalum scrobiculatum*)	Head smut	*Sorosporium paspali* McAlp	No change	Externally seed-borne
Kasi (*Coix lacryma-jobi*)	Grain smut	*Ustilago coicis* Bref.	No change	Not known
	Smooth spored grain smut	*Ustilago lachryma-jobi* Mundkur	..	Not known
Sugarcane (*Saccharum* spp.)	Stem smut	*Ustilago scitaminea* Syd.	*Ust. sacchari* Rabenh.	Through infected setts and nodes
	Covered smut	*Sphacelotheca sacchari* (Rabenh.) Cif.	*Ust. sacchari* Rabenh.	Not known
Mustard (*Brassica* spp.)	Root-gall smut	*Urocystis brassicae* Mundkur	*Uro. coralloides* Rostr.	Soil-borne

Summary

A list giving the common names of smuts, their scientific names in conformity with the International Rules of Botanical Nomenclature and names according to previous practice, together with the probable modes of their transmission, has been compiled so as to standardize the names.

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